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FINAL REPORT

MODIFICATION OF AN ASTRONAUTS MOCK-UP TOOL KIT

APRIL 1971

PREPARED FOR

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

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FOREWORD

This report was prepared by the Martin Marietta Corporation under Contract NAS8-26448, "Modification of an Astronaut's Mock-Up Tool Kit", for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the Technical Direction of Mrs. Anne Folsom, Quality and Reliability Assurance; and Mr. Issac Edmond, Jr., Manufacturing Engineering.

ABSTRACT

This report describes the effort accomplished under Contract NAS8-26448 in the development of astronaut support equipment for use on future missions involving inflight maintenance tasks. Several items of non-flight hardware were developed during this contract, including an astronaut's tocl kit and tools, a repair kit designed to seal leaks in fluid systems, and a fluid removal tool used in the repair of fluid systems. A demonstration test panel was built for inflight maintenance simulation tests using the above equipment.

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I. INTRODUCTION

The purpose of this contract was to define, develop, and build several items of prototype astronaut support equipment for inflight maintainable subsystems on future manned orbital missions of extended duration. The primary items developed under this contract were: (1) an Astronaut Tool Kit complete with tools and other support and checkout equipment; (2) a method to repair and seal external leaks in fluid systems; (3) a fluid removal concept including a fluid removal tool that was built and tested; and (4) a demonstration test panel fabricated for the purpose of conducting an inflight maintenance simulation test using the above equipment.

NASA is presently planning several modes of manned flight that will involve up to 12 astronauts, with orbital missions that are designed for a duration of ten years in space. The realization of a ten-year mission in space dictates a new approach to subsystem design. In previous and current space efforts, the subsystem reliability was satisfied by component redundancy and rigorous component testing. This approach was practical because of the relatively short mission durations. For very long missions, the crew must be able to repair the system to maintain its original integrity. In order to arrive at a repair capability in space, several areas of technology must be satisfied. This program attempts to answer some of these problems; namely astronaut tools, fluid leak repair, and fluid removal.

The objectives of this contract were accomplished in five phases:

1) A task to identify the requirements and criteria for each item of hardware;

2) An evaluation and definition of the applicable concepts;

3) A development program to verify the concepts and to gain data;

4) Design reviews followed by design of the hardware; and

5) Fabrication and delivery of the functional prototype hardware.

This final report describes the work performed for each major item of prototype hardware, together with all findings, data, and conclusions.

II. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

This chapter provides a brief summary and description of each major unit of hardware that was developed under this contract. The specific details and supporting data may be found in the body of the report.

1. Astronaut Tool Kit

One of the primary objectives of this contract was to develop and build a full-scale prototype tool kit that could be used for space maintenance of subsystems on future manned orbital missions; with primary emphasis on the requirements of the Skylab program, Space Station, and Shuttle.

The total tool usage concept developed during this program involves three parts: (1) a central stowage area for tools (Stowage Locker), (2) transfer of tools and spares to the work station, and (3) restraints and auxiliary equipment required at the work station. Hardware was developed for each aspect of this concept.

The tool kit is designed for stowage in a stowage locker, and is basically a cabinet with a sliding drawer approach to tool storage. The tool kit contains an integrated filled-out set of standard commercial-type tools, procedures, consumables, tool and spare parts carriers, and general purpose tools necessary to perform first level maintenance tasks. The tool kit and tools were designed for IVA use, with 90 percent of the maintenance tasks performed in a shirtsleeve mode, and 10 percent in a pressurized IVA space suit. The tool kit may be used in either zero-g, partial-g or a one-g environment.

The five drawers of the tool kit are constructed of aluminum and are sized for the specific tools and/or consumables located in each drawer. They are labeled to indicate the general contents of each drawer, and the titles were designed for simplicity, rather than a complete description or list of each tool contained in their respective drawer. The tool kit is 11.34 inches high, 15.90 inches wide, and 9.6 inches deep. The total unit, with commercial-type tools, weighs approximately 37 pounds. Included within this envelope is a handle, located on top of the cabinet, that is used for translation and handling.

Each of the first three drawers has a sponge rubber retention system that has a specific cut-out for each tool. This serves as a vibration attenuator during launch, provides a specific location for each tool, and each tool is readily visible when the drawer is opened. The cut-outs also serve the purpose of identifying lost or misplaced tools. Because of their unusual size and shape, the equipment located in drawers 4 and 5 are restrained by velcro straps.

Each drawer can be opened by a simple wire handle attached to the front of each drawer. Drawer number four has a lock device that locks the drawer to the main cabinet to allow removal of the total tool kit from the stowage locker in zero-g conditions.

A detent system maintains each drawer in the normally closed position by means of a friction fit. In the open position the drawer detent must be released before the drawer can be removed from the cabinet. This type of positive detent is required to prevent a free pull of the drawer from the cabinet, and thus a loss of tools and possible damage to other spacecraft equipment. The detent mechanism is actuated by a trigger-type mechanism located on each side of the drawer, and will allow removal of the drawer with a one-handed operation.

The tool kit was designed so that tools could be selected from a drawer, placed in the tool carrier, and taken to the work station; or a selected drawer(s) of tools could be transported to the work station as a unit; or for unscheduled maintenance, where exact tool requirements were unknown, the astronaut could take the entire tool kit to the work site.

Spares will be transported to the work station in a spares translation carrier which is a simple bag-type carrier, very much like a shopping bag. The spares carrier can be translated by a one-handed operation using the handle, or the astronaut's hands can be left free during translation by using the shoulder tether.

The tool kit contains 66 hand tools, 7 items of miscellaneous support equipment, and 10 articles that fall within the category of consumables.

This tool list is an integrated set of tools that is largely based upon the maintenance requirements of the Skylab cluster. In addition, the tool list is "filled-out" above and beyond the exact maintenance tasks anticipated so that unforeseen contingencies or emergencies can be handled. Certain general application tools are also included in the kit. The astronauts have recommended that the tools should be standard commercial tools of the type that "we are used to using on earth".

A mock-up of a stowage locker compartment was fabricated so that stowage of the tool kit could be demonstrated. The Skylab Orbital Workshop stowage locker configuration was used since it is a typical example of the type stowage compartment that may be expected on future orbital spacecraft.

The mock-up locker has sufficient detail to show the clearances to be expected and also shows a concept of a lock that could be used to retain the tool kit in the locker in a zero-g environment. This mock-up will be used to evaluate the total tool usage concept under simulated zero-g tests (KC-135 aircraft).

2. Fluid Removal Tool

For any future inflight maintenance plans being developed for long-duration missions, the capability must exist to repair fluid subsystems. Before a fluid component or system can be replaced or repaired, the fluid within the system, in the area of the repair section, must first be removed or contained. After component replacement, the system must be recharged and bled-in to remove trapped air.

As part of this contract, a unique fluid removal tool was conceived, developed, and a prototype fabricated. This fluid removal tool performs all of the operations required for fluid system maintenance; (1) fluid removal, (2) intermediate storage of the fluid that was removed, and (3) fluid refill of the system after repair. The tool is hand operated and uses the mechanical fittings, that are a part of the system, as the point of fluid removal.

It is felt that this concept provides a significant advance in new technology, and that this concept can be used for other applications. The unique features of this tool are:

1) The tool is simple in design with inherently high reliability;

2) It requires no additional interfaces (power, fluid storage tanks, nitrogen purges, etc.) for operation;

3) The procedure is straight-forward and should not require extensive astronaut training;

4) No special equipment or hardware is required in the fluid system at the point of fluid removal (such as valves, test ports, disconnects, etc.);

5) The tool can be used in either a one-g, partial-g, or zero-g environment;

6) It can be used for most non-toxic fluids.

The fluid removal tool assembly consists of a fluid collection clamp, fluid removal pump, valve and hose assembly, and the flexible storage container. The principle of operation is based upon controlled leakage past the seal of a mechanical fitting, such as is found in any maintainable system.

The fluid collection clamp is clamped onto the tube next to the fitting and forms a cavity to channel the fluid into the suction pump. The "fitting" nut is loosened, which allows leakage of the fluid past the seal, between the tubing and the fitting nut, and into the collection cavity. The hand-operated pump provides the negative differential pressure necessary to establish the leak and direct the flow of liquid from the collection cavity to the storage bag.

After the fluid system repair is accomplished, the storage container is used to recharge the system. The flexible storage container also acts as a manual fluid pump and a liquid/gas phase separator. The hydrophobic screen on the storage bag will allow vapor or air to pass through the screen but will not allow liquid to escape; thus the screen acts as a vent and a phase separator. The flexible container, with the fluid in it, can be rolled up like a toothpaste tube or slowly squeezed to push the vapor or air out the hydrophobic screen to separate the gas from the liquid. After the gas is separated out, the container is either squeezed or rolled up, forcing the liquid back into the fluid system, thus completing the cycle.

The pump is operated by a hand pumping action and has the capacity to displace 3.38 cubic inches per stroke. The basic pump design consists of a closed bellows chamber with inlet and outlet check valves. All of the materials in the assembly that interface with the fluid are compatible with most fluids.

The storage container is constructed from 3 mill clear teflon, so that the astronaut can see the contents of the container. The container was sized for 1500 milliliters, which is equivalent to that volume contained in 300 feet of 1/4-inch tube.

3. Leak Seal Repair Kit

The ability to repair external leaks in a fluid system is vital to the success of any long-duration manned mission. One of the tasks on this program was to establish a leak repair technique that an astronaut could use to repair leaks within a spacecraft.

The primary guidelines for this development were; (1) the technique must be compatible with the fluid and cabin atmosphere, (2) the operation should be simple, dependable, and should minimize the requirement for interfaces, power, etc., and (3) should be adaptable to as many leakage situations as possible. Water-based systems were selected for the baseline fluid since they represent approximately 80 percent of the fluid systems that will be used on the Space Station.

This development program consisted of three phases; (1) a conceptual phase to identify feasible techniques; (2) an analysis phase, followed by (3) test phase.

A total of 24 different sealing techniques, and various combinations were considered. Many were dropped from consideration because of obvious disadvantages. Preliminary tests were conducted on the remaining candidate techniques, and a comprehensive series of tests were conducted for the most promising method.

In this program it was concluded that the simplest and most adaptable method of sealing leaks was a process using anaerobic adhesive and followed by overwraps of tape using the following procedure:

1) Apply a primer (MIL-S-22473C1) to the metal surface;

2) Apply anaerobic adhesive to the leak area;

3) Wrap the area with self-vulcanizing silicone tape;

4) Overwrap with pressure sensitive teflon tape;

5) Allow the adhesive to cure prior to resuming system operation (15 minutes at room temperature).

The above method is simple, can be accomplished by an inexperienced person, requires no special tools, and can be performed in less than five minutes. The only constraint is that the system must be shut down and depressurized prior to sealing the leak. For most systems, this is normally considered to be a standard operating procedure anyway.

The best test results were obtained during the repair of leaks in tubes and fittings. Although the tests conducted on tanks and valves were not as spectacular, the method shows promise. The level of effort on this phase of the contract was to establish a technique that could be adapted to spacecraft use. The testing performed was primarily of a quantitative nature sufficient to prove the concept. It is recommended that further development and study be performed to qualify this concept and others that are applicable to the technology of leak repair in space.

4. Inflight Maintenance Simulation Test

A simulation test panel was constructed for the purposes of testing various elements of the tool kit, the leak repair kit, and the fluid removal tool. The tests will be performed by NASA, after the conclusion of this contract, on an air bearing simulator and then in a KC-135 aircraft to simulate a zero-g environment.

The test panel has a pressurized (75 psig) water system that will be used to test fluid removal, fluid component removal/replacement, leak repairs, and to supply fluid for the surface tension tests.

The test panel also contains a fastener task panel with several fasteners designed to test human performance in zero-g, to evaluate tool operation, and for an evaluation of common fastener design in a zero-g environment. The task panel contains screws, bolts, and roll pins that range in size from a 10-32 screw to a 7/16-inch bolt. Tools that will be used include socket wrenches, punches, hammer, screwdriver, flare nut wrench, connector pliers, diagonals, an electrical crimping tool, and a torque wrench.

The major tasks that will be performed during these tests are:

1) Fluid removal in zero gravity;
2) Fluid component removal;
3) Fluid component replacement;
4) Fluid fill and bleed;
5) Leak repair of tubes and fittings;
6) Evaluation of tool usage on the fastener task panel;
7) Evaluation of surface tension effects in zero-g for application to space maintenance;
8) Human performance in zero-g while performing maintenance tasks;
9) An evaluation of the design, human factor aspects, and application of the tool kit, tool kit contents, the fluid removal pump, and the leak seal repair kit.

B. RECOMMENDATIONS

In the performance of a contract in an area of new and important technology, such as inflight maintenance, it is incumbent that the participants identify those areas of technology that require future development. The formulation of programs such as the Space Station, Shuttle, and other future manned missions depend upon the proper development of future technology so that a solution to problems is developed on a timeline consistent with its needs.

Space maintenance is of prime importance to the fulfillment of the long-duration mission, and requires the proper direction and development to meet those future requirements.

Seven specific areas of future technology are outlined below. It is recommended that further effort be continued in these specific areas.

1. Fluid Removal, Containment, and Decontamination

On this contract a prototype of a unique concept for fluid removal was developed. This concept should be carried further to establish; (1) an advanced design beyond the prototype stage, (2) an application analysis for fluids other than water, and (3) further testing to define operating and human factor parameters.

In addition to the above concept, a study and development program should be initiated to consider other methods of fluid removal, transfer, and containment, since different fluids and systems may require a different approach. Factors such as toxicity, bacteria control, temperature limits, and compatibility must be considered.

Propellants provide an extreme and different set of conditions for space maintenance. Better methods of fluid removal and decontamination must be developed for the safety of the crew.

2. Leak Prevention and Repair

The level of effort on this contract was to establish a technique for leak repairs that could be adapted to spacecraft use. The testing performed was primarily of a quantitative nature sufficient to prove the concept. It is recommended that further development of this technique be considered. Tests should be conducted on other candidate spacecraft fluids, a more extensive compatibility study should be conducted for the various fluids, and quantitative tests should be conducted to determine the effects of leakage rates, shape, configuration, etc.

During the development of this leak repair technique, it was realized that no one method can be all-encompassing for all types of leaks - large and small, for various shaped configurations, and for all fluids. Therefore, it is recommended that a general study of leak repair techniques be performed to develop techniques and solutions for all of the leaks, systems, and fluids that are programmed for Shuttle and the Space Station.

3. Repair, Refurbishment and Recertification Facility

In order to perform maintenance, checkout, and repair of subsystems in space, a general-type repair and recertification facility is required. This workshop-type facility would be used for all of the subsystems requiring onboard maintenance such as fluid/mechanical, electronic, communications, optics, power, and experiments. It is recommended that a definition-type study be initiated to define the requirements and configuration of such a facility.

4. Space Maintenance Criteria and Guidelines

In order to meet the mission requirements of future long-duration manned missions, space maintenance must become a companion technology to the design of subsystems. Strong emphasis is required by NASA early in the program; they must provide direction, and also place requirements on the various contractors to insure the proper design of maintainable systems.

An integrated set of criteria and guidelines for inflight maintenance is required if common and optimum subsystem designs are to be expected from among all of the contractors involved. It is recommended that a handbook for space maintenance be developed first - with a program of continual update; followed by a specification detailing the requirements for maintainable subsystem design.

5. Commonality Study

Without some measure of hardware commonality on such a mission as Space Station, the inflight maintenance requirements, tooling, repair kits, astronaut training, and spares will become impossible. A study is required to define those areas where commonality can best be implemented, and to provide detailed recommendations on those commonality configurations best suited to maintenance, spares, etc.

6. Space Maintenance Test Bed

A non-flight test bed is required so that a design and test program can be conducted to configure, evaluate, and gain test data on different configurations of maintainable subsystems. The test bed should involve all of the subsystems requiring maintenance such as electronic, fluid/mechanical, experiments, etc. The test bed would be a one-g simulation facility, but detail tests could be conducted in neutral buoyancy and on KC-135 aircraft. The non-flight test bed would be the most economical method of obtaining physical and human factor-type data on inflight maintenance. In addition to being an evaluation center, the test bed and its subsystems could be used for training purposes.

7. Multimeter

A multimeter has been identified on this program and the Skylab program as a requirement for the checkout, verification, and fault detection of electrical circuits. The multimeter supplied in this tool kit is of the hand-held type and is a commercial unit. Flight-qualified multimeters are not presently available and development of a multimeter for inflight maintenance is recommended.

III. ASTRONAUT TOOL KIT

One of the primary objectives of this contract was to develop and build a full-scale prototype tool kit that could be used in space maintenance of subsystems for future manned orbital missions. The Astronaut Tool Kit development was based upon the requirements of the Skylab program, Space Station, and the Shuttle; with primary emphasis on Skylab.

The Astronaut Tool Kit, Figure III-1, is a standard housing-type tool kit with slide-out drawers. The tool kit contains those tools, consumables, procedures, spare parts carrier, tool carriers, and that checkout and repair equipment necessary to perform first level inflight maintenance tasks. The tool kit is constructed of aluminum and is 11.34 inches high, 15.90 inches wide, and 9.6 inches deep. The total unit, with commercial-type tools, weighs approximately 37 pounds.

The total tool usage concept involves three parts: (1) a central stowage area for tools (stowage locker), (2) transfer of tools and spares to the work station, and (3) restraints and auxiliary equipment required at the work station. The tool kit was designed so that it could be stored in a locker similar to the Skylab Orbital Workshop stowage locker during launch and when not in use. Thus, the tools and equipment needed for inflight maintenance would be located in one convenient location. As part of this contract, a mock-up of one stowage locker compartment, Figure III-2, was fabricated so that stowage of the tool kit could be demonstrated. The mock-up locker has sufficient detail to show the clearances to be expected and also shows a concept of a lock that could be used to retain the tool kit in the locker in a zero-g environment. This mock-up can be used to evaluate the total tool usage concept under simulated zero-g tests (KC-135 aircraft).

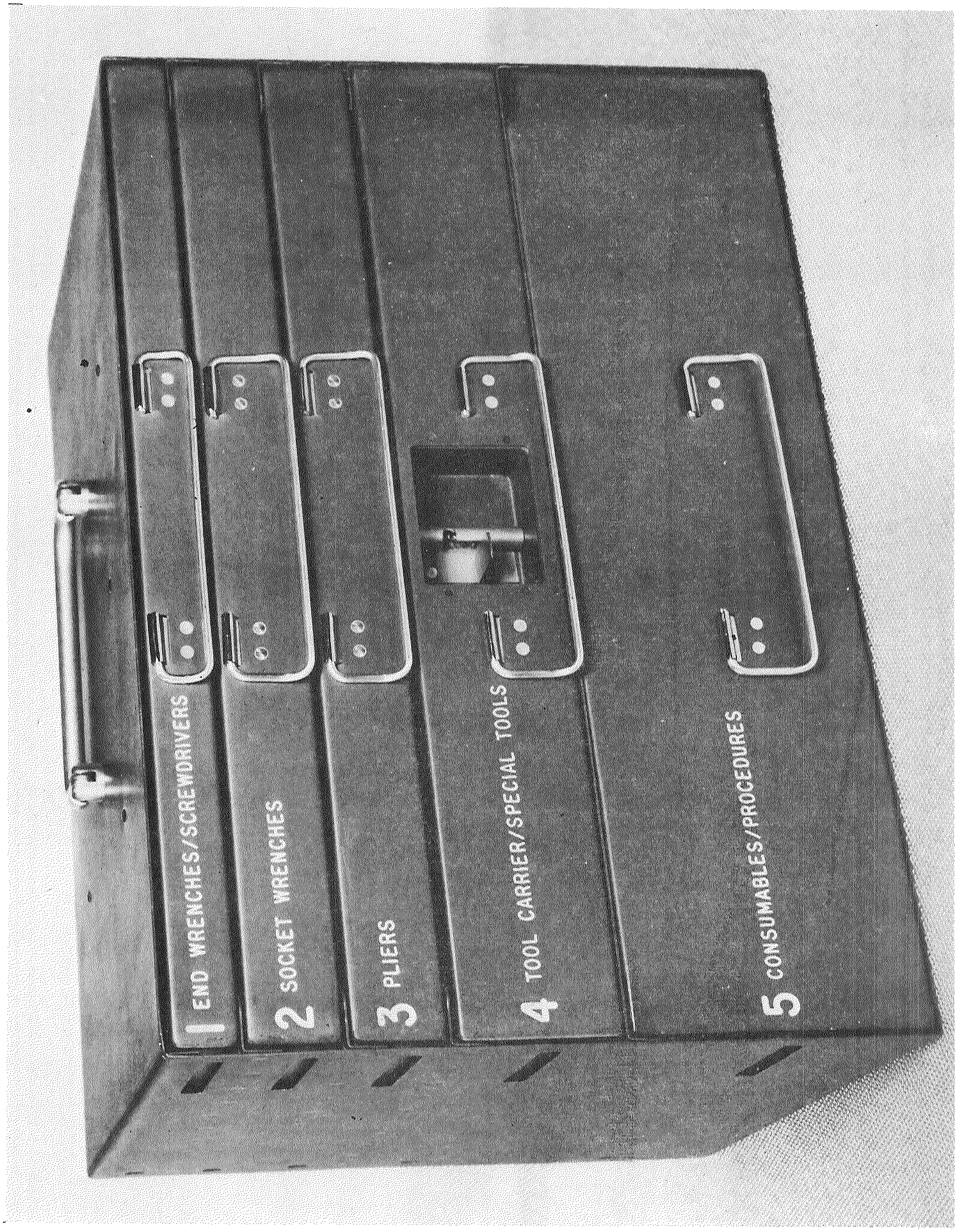


Figure III-1 Astronaut Tool Kit

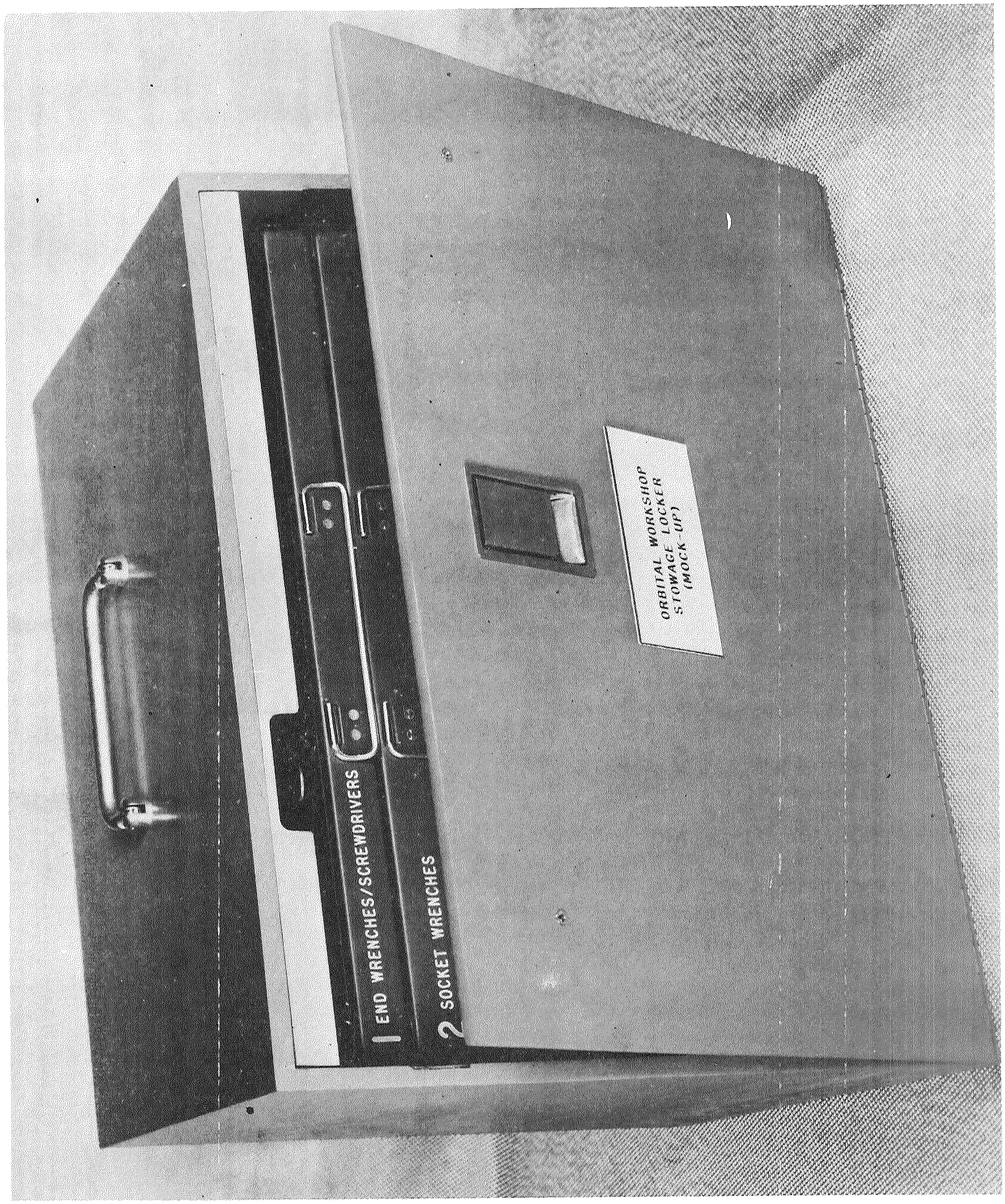


Figure III-2 Stowage Locker, Mock-Up

The tool kit was designed so that tools could be selected from a drawer, placed in the tool carrier, Figure III-3, and taken to the work station; or a selected drawer(s) of tools could be transported to the work station as a unit; or for unscheduled maintenance, where exact tool requirements were unknown, the astronaut could take the entire tool kit to the work site. Spares will be transported to the work station in a spares translation carrier, Figure III-4, which is a simple bag-type carrier, very much like a shopping bag. The spares carrier can be translated by a one-handed operation using the handle; or the astronaut's hands can be left free during translation by using the shoulder tether.

Various articles of equipment are provided in the tool kit for use at the work station, and include procedures, a zero-g restraint for the tool kit, a vacuum mount vise, and other equipment.

A. TOOL KIT BASELINE AND GUIDELINES

The design of the tool kit was directed by several guidelines and included the following sources:

1) Contract statement of work and initial program guidelines;

2) Review of concepts, and subsequent recommendations by Astronauts William B. Lenoir and Donald L. Lind;

3) Meetings with crew systems test subjects;

4) Review of simulation test films, data, and effort performed under Contract NAS8-24296, "Portable Astronaut Test Kit";

5) Skylab crew member recommendations during Crew System Reviews.

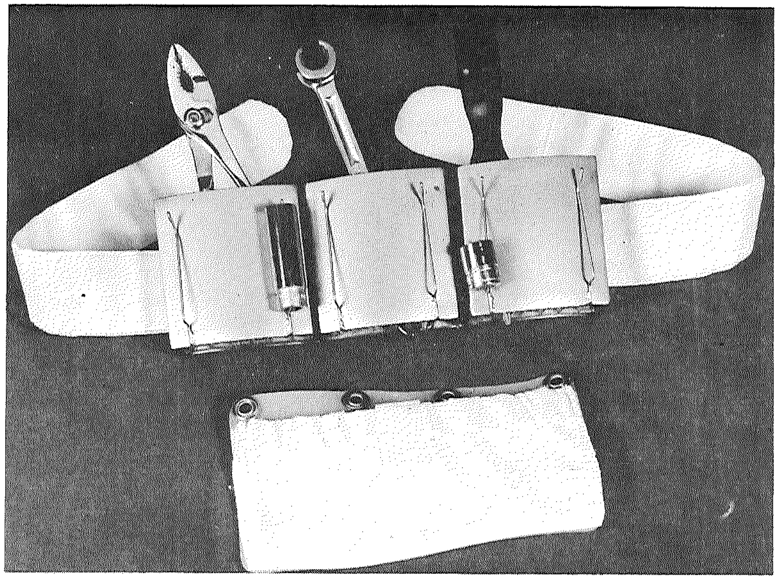


Figure III-3 Tool Carrier

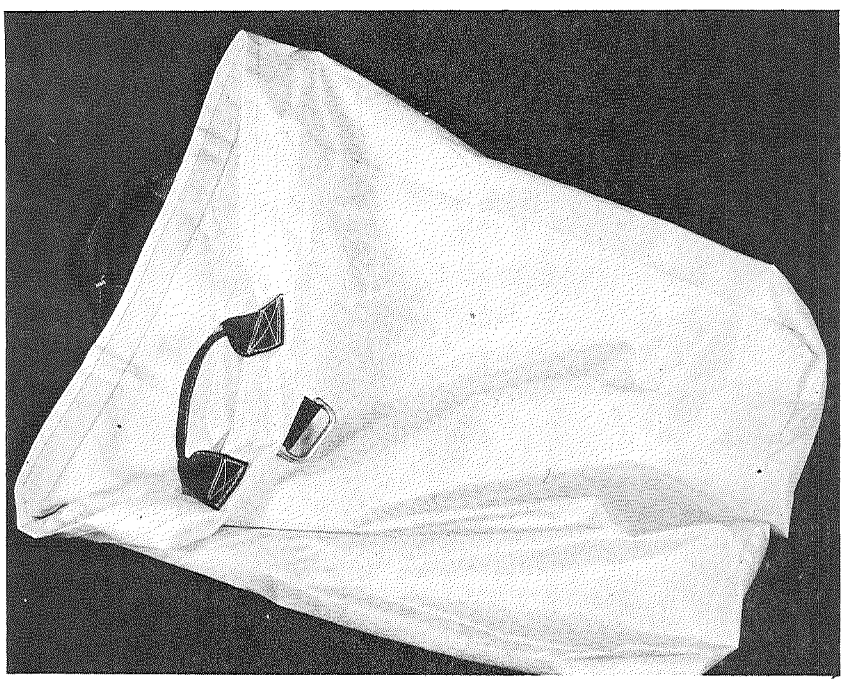


Figure III-4 Spares Translation Carrier

1. Tool Kit Development Guidelines

At the beginning of this program, a review was conducted with the NASA Technical Monitors to establish guidelines and give direction to the development of the tool kit. The following guidelines are the result of this review; they also contain some constraints that were extracted from the contract statement of work:

1) The tool kit configuration shall be directed towards the potential inflight maintenance requirements thus far identified for the Skylab program, Space Station, and Shuttle; with primary emphasis on the Skylab requirements;

2) The contractor will use existing analysis data developed on Contract NAS8-24296, and from the Skylab, Space Station and Shuttle programs; rather than performing special analyses, to establish tooling requirements;

3) Assume availability and use of maintenance-support equipment identified on the Skylab A Stowage List (e.g., portable floodlights, astronaut foot restraints, and handholds) to supplement the tool kit capability;

4) Emphasis will be placed upon tools of a general-use capability, rather than special, one-time, or specific subsystem use types;

5) Assume the use of the tool kit in an IVA-only environment, with 90% of maintenance operations performed in shirtsleeve and 10% in a pressurized IVA space suit;

6) The mock-up tool kit shall be developed for zero-gravity use and demonstration (rather than one-gravity);

7) Tool kit packaging as developed for spacecraft translation shall:

   a. allow passage through minimum apertures, hatchways, airlocks, etc., of a typical spacecraft system;

   b. require translation services of no more than one astronaut;

   c. leave the astronaut's hands free, if possible, with one hand free at all times;

8) Tools should be as near flight configuration as possible; however, development emphasis shall be placed upon the tool kit packaging and development rather than individual tool design;

9) Wherever possible, tools and tool kits should be constructed of flight-compatible materials;

10) The tool kit shall be primarily developed for performance of first-level maintenance involving removal/replacement, and limited in-place repair.

11) Miscellaneous handtools groundrules:

   a. open-end wrenches are not desired; box-end wrenches, flare nut wrenches, or ratcheting box wrenches are preferred;

   b. backup or spare tools may be necessary to support loss or accidental damage of high-use tools;

   c. consider incorporation of "short-set" groups of tools to "fill out" tool kit complement, especially where additional sizes of tools would be useful to cope with unforeseen contingencies;

12) During mock-up development, considerations shall be given to demonstration and test results, and review comments relative to the Portable Astronaut's Test Kit delivered under Contract NAS8-24296;

13) A suitable version of a portable, handheld-size volt-ohm-Millimeter will be incorporated that is functional, and establishes potential downstream uses of such equipment for Space Station second and third levels of maintenance;

14) Miscellaneous tool kit groundrules:

a. The tool kit and its total contents shall not exceed 60 pounds and shall be sized to fit into a Skylab I stowage locker;

b. Tool kit design will emphasize simplicity, ease of operation and translation, safety, minimum repair time, and multi use;

c. The assembled kit will have the capability for tethering and attachment;

d. Latches, connectors and/or fasteners will be easily operated under pressure-suited conditions.

2. Crew Systems Recommendations

Two of the most important criteria in the design of the tool kit were: (1) simplicity in design, and (2) consideration of crew systems engineering aspects. In order to gain first-hand data on the latter of the two criteria, meetings were conducted first with crew systems test subjects, and then with two members of the Skylab astronaut crew. Data was also received from the Skylab Crew Systems Review.

A review of the tool kit concepts was conducted on October 14, 1970 with astronauts Dr. William B. Lenoir and Dr. Donald L. Lind. The main comments received during this meeting were as follows:

1) The general approach of central tool stowage in the OWS locker, translation with a waist tool carrier, an in-place maintenance with waist-or-thigh-mounted tool carriers appears satisfactory;

2) The sliding-drawer approach is satisfactory;

3) In addition to taking tools to the work site in the tool carrier, the capability should exist to take the entire tool kit, or any or all of the drawers if desired, for use during emergencies when exact tool requirements are not known;

4) It may be advisable to have a number of smaller tool kits in the Command Module, Multiple Docking Adapter, and the Orbital Workshop. Packaging for translation would be simplified, simpler forms of storage packaging would be required, and tool kits would be tailored for jobs within their "region";

5) A restraint device should be provided to restrain the tool kit, or individual drawers, at the work site;

6) An integrated tool list is required, rather than only tools suited to particular and known maintenance tasks. The tool kit should be a complete filled-out tool set for possible contingencies. Specific tools requested were a hammer, punch, vise grips, crescent wrench, diagonal cutting pliers, mechanical fingers, and a hex head ratchet with 15 degree rotation;

7) The tools should be exposed to view when the drawers are opened. The sponge retention system also emphasizes the proper location for each tool, and whether or not a tool is missing;

8) Nomenclature should be simple and straightforward. Tool labels should be descriptive as to kind and size rather than a coded identifier;

9) The tool kit should contain standard, commercially available tools. Special design tools should be avoided if possible;

10) A spare parts carrier should be included so that spares may be translated to the work site. The "shopping bag" approach is suitable.

B. TOOL KIT DESIGN

The Astronaut Tool Kit is designed for stowage in a stowage locker, and is basically a cabinet with a sliding drawer approach to tool storage. The tool kit contains an integrated full set of standard commercial-type tools, procedures, consumables, tool and spare parts carriers, and general-purpose tools such as the bench vise and multimeter. Simplicity in design and operation were underlined as the chief requirements for the design of this tool kit.

Although this contract called for the delivery of mock-up hardware, every effort was made to deliver hardware that was as close to flight-type hardware as was possible within the budgetary limits of the contract. When possible, the materials used were of the type that could be or are qualified for spacecraft use. In every case the design is such that space compatible materials could be substituted without affecting function or performance. For instance, the sponge rubber retention system in the tool kit drawers is fabricated from a sponge rubber called Armaflex. Although Armaflex is not compatible, it has the same appearance, color, consistency, and durometer as Mosite, which is compatible.

The tool kit cabinet is constructed of aluminum and is near flight weight. The cabinet and drawers were designed for zero-g operation rather than for one-g demonstration or training. The outside dimensions are 10.84 inches high, 15.90 inches wide, and 9.6 inches deep. A handle is located on top of the cabinet for translation and handling, which raises the total height envelope to approximately 11.34 inches. The handle is friction loaded so that it will remain in the "down" position when stowed in the storage locker.

The five drawers are constructed of aluminum and are sized for the specific tools and/or consumables located in each drawer. They are labeled to indicate the general contents of each drawer, and the titles were designed for simplicity, rather than a complete description or list of each tool contained in their respective drawer. The titles for each drawer are:

1) END WRENCHES/SCREWDRIVERS

2) SOCKET WRENCHES

3) PLIERS

4) TOOL CARRIER/SPECIAL TOOLS

5) CONSUMABLES/PROCEDURES

Each of the first three drawers has a sponge rubber retention system that has a specific cut-out for each tool. This serves as a vibration attenuator during launch, provides a specific location for each tool, and each tool is readily visible when the drawer is opened. The cut-outs also serve the purpose of identifying lost or misplaced tools. Because of their unusual size and shape, the equipment located in drawers 4 and 5 are restrained by velcro straps. Nomenclature is used to identify the tool sizes, for such tools as sockets.

Each drawer is opened by exerting a pulling force on a simple wire handle attached to the front of each drawer. Drawer number four has a lock device that locks the drawer to the main cabinet to allow removal of the total tool kit from the stowage locker in zero-g conditions. Removal can be easily accomplished by locking drawer number four, and pulling on the drawer handle.

A detent system maintains each drawer in the normally closed position by means of a friction fit. In the open position the drawer detent must be released before the drawer can be removed from the cabinet. This type of positive detent is required to prevent a free pull of the drawer from the cabinet, and thus a loss of tools and possible damage to other spacecraft equipment. The detent mechanism is actuated by a trigger-type pull, that pulls a simple direct-acting cam that in turn lifts the detent from the slots in the tool kit cabinet. A "trigger" mechanism is located on each side of the drawer, and will allow removal of the drawer with a one-handed operation, which is necessary for zero-g operation.

C. STOWAGE LOCKER

A mock-up of a standard stowage locker, similar to the lockers proposed for use on Skylab, was fabricated to demonstrate stowage of the tool kit. The locker will also serve as a test article during the zero-g simulation tests to evaluate clearances and fit between the tool kit and the locker.

The mock-up locker has the same internal dimensions as the Skylab OWS stowage locker, and also utilizes duplicate hardware for the door lock.

A retention lock, Figure III-5, restrains the tool kit cabinet within the locker while the drawers are being pulled out or removed. This lock is necessary since friction forces are absent in a zero-g environment. The tool kit can be easily removed from the locker by pressing up on the retention lock lever. Since the lock is a simple direct-acting lever, the lock could be easily pried open in the event of an unforeseen failure.

D. TOOL KIT CONTENTS

The Astronaut Tool Kit contains 66 hand tools, 7 items of miscellaneous support equipment, and 10 articles that fall within the category of consumables. The tool list is included as Table III-1, and the consumables are listed in Table III-2.

This tool list is an integrated set of tools that is largely based upon the maintenance requirements of the Skylab cluster. In addition, the tool list is "filled-out" above and beyond the exact maintenance tasks anticipated so that unforeseen contingencies or emergencies can be handled. Certain general application tools are also included in the kit.

During the initial concept reviews and later during the Crew Systems Reviews, the astronauts recommended that the tools should be standard commercial tools of the type that "we are used to using on earth". Although they initially requested a tether attachment on each tool, they later reversed this request. They did state that they did not want multiple-use-type tools. They also requested that each tool that is size oriented, such as a socket, should be labelled with simple and straightforward nomenclature, rather than a coded identifier.

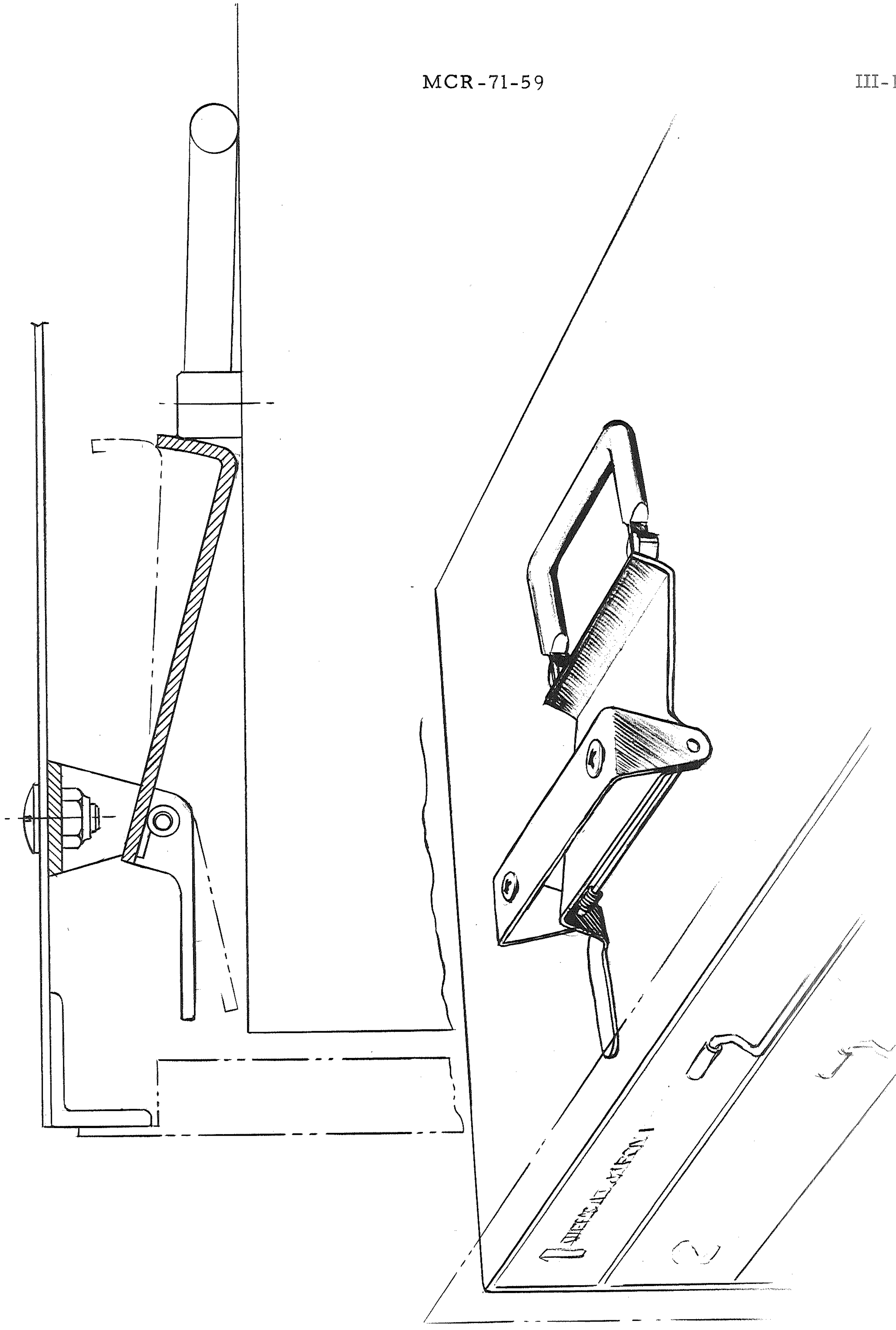


Figure III-5 Stowage Locker Retention Device

Consideration was given to requirements for redundancy of high usage tools and to the environmental conditions in which the tools are to be used. Redundancy was accomplished in some cases by supplying sockets of the same size in varying lengths. No special modifications to tools were considered necessary for environmental conditioning other than special materials for a low sparking hazard. Initially there was a requirement on the Skylab program for non-sparking tools; but this was later dropped. In this tool kit, the tools that are most apt to generate sparks, such as the hammer and punch, were fabricated from a non-sparking material.

In addition to the hand tools required for inflight maintenance, certain tools and/or specialized repair kits are required for a full spacecraft maintenance capability. Generally, these repair kits are of considerable volume and should be stowed directly in a stowage locker, rather than in a tool kit. It is recommended, however, that all of the tools and repair kits used for inflight maintenance be stowed in adjacent lockers, or in one central area.

The requirements of this contract were to develop tool packaging and tool kit concepts, rather than to place emphasis on the specific design of tools. In addition, the Skylab tool requirements were used as the primary source for selection of a tool list. The maintenance requirements on this program were initiated after the equipment was designed, and hence, not all of the tools are of the type that are recommended for future inflight maintenance. In general, we do not recommend the use of conventional screwdrivers since the bolt heads are easily damaged, and also placement and rotation in a zero-g environment is difficult. The use of phillips head screwdrivers is definitely not recommended.

Socket head cap screws appear to be well suited for zero-g use, but hexagon bits below 1/8 inch are not recommended because of stripping in the socket or on the flanks of the hex bit. In general, 3/16 inch or larger hexagons are preferred.

A speed handle is required for zero-g use, but a standard type speed handle does not appear to be well suited to zero-g operation because of the requirement for a two-handed operation. A manual "fly-ball" inertia-type tool as was developed by the Manufacturing Engineering Laboratory, NASA-MSFC, appears to fulfill the requirement.

Two philosophies exist on the sizing of torque wrenches. One is that torque wrenches are only required to protect the equipment, and in this case the torque wrench is sized (5-50 inch-pounds) so that the torque applied to small fasteners is limited. The other consideration is that the torque wrench should be sized (5-150 inch-pounds) to handle all torques specified for the equipment being repaired. The 5-150 inch-pound torque wrench was selected for this tool kit.

Double end, flare nut wrenches were selected because they have the advantages of a box end wrench as far as placement and fastener restraint in zero-g, and also the flare nut wrench is ideal for the removal of fittings in a fluid system. The double-ended wrench provides the required hex sizes with half the number of tools and accompanying weight.

In general it appears that more research, design, and zero-g testing is required on the subject of fasteners and tools for zero-g use. A great deal of the existing knowledge on common fasteners should be adaptable to such a program.

The crescent wrench was included as a general-purpose type tool. So were the hammer, pliers, vise grips, flex grip-it tool, tape measure, inspection mirror, and bench vise. The tool set was "filled out" beyond the Skylab requirements in the areas of sockets, flare nut wrenches, and pliers.

The vacuum base bench vise provides an attractive attachment device for zero-g use since it only requires a semi-flat mounting surface. Other methods of mounting a bench vise generally require a mounting edge or holes that are specific in nature, whereas the vacuum base is more adaptable.

The multimeter is a general-purpose tool used for fault detection and verification of electrical circuits. The multimeter supplied in this tool kit is of the hand-held type and is a commercial unit. Flight-qualified multimeters are not presently available and development of a multimeter for inflight maintenance is recommended.

The spares translation carrier is used to translate spares from the stowage locker to the failed subsystem, and then for return of the failed item. It may also be used to transport other commodities, repair kits, drawers of tools, etc. The spares carrier, Figure III-4, is a very simple design, similar to a shopping bag. It is constructed from Beta cloth, and is approximately 24" x 20" x 3". A velcro zipper is located at the top edge and provides a simple closure to restrain objects within the carrier. The carrier can be translated by a one-handed operation utilizing the carrier handles, or by a shoulder tether which is included in the tool kit. The tether has quick-release parachute-type fasteners that attach to D-rings located on the spares carrier.

The tool carrier, Figure III-3, is designed to carry tools from the tool kit, located in the stowage locker, to the work site. Two sets of tool carriers may be worn on the waist, or one set may be thigh-mounted, depending upon the astronaut's preference. The waist and thigh belts are constructed from velcro pile, whereas velcro hook is bonded to the backs of the tool carriers. This allows the astronaut to position the tools anywhere on his waist, and to easily attach or remove the carriers from the belt. Each assembly consists of three cases that are hinged, thus allowing for conformity to the waist, or the thigh.

The unique feature of the tool carrier design is the "fingers" that are bonded in each of the cases. These "fingers" allow easy placement of the tool in the case and yet restrains the tool even with minus-g loading. The main feature is that the restraint is universal, and the astronaut does not have to place the tool in a predetermined slot, look at the tool, or work any type of tether arrangement, etc. Tools may be inserted into the cases either from the top or the bottom. Sockets and larger tools such as hammers and crescent wrenches can be hung on the spring clips located on the front side of the cases.

The parts carrier, Figure III-6, is a "pocket-like" arrangement that is attached to the spring clips on the tool carrier and is used to hold fasteners, small parts, etc., while performing a repair at the work site. A "pocket"-type concept was selected over other concepts because a large quantity of fasteners must be retained upon initial activation of the cluster and again for activation of the experiments. The top edge of the parts carrier has an elastic band to restrain the parts in zero-g.

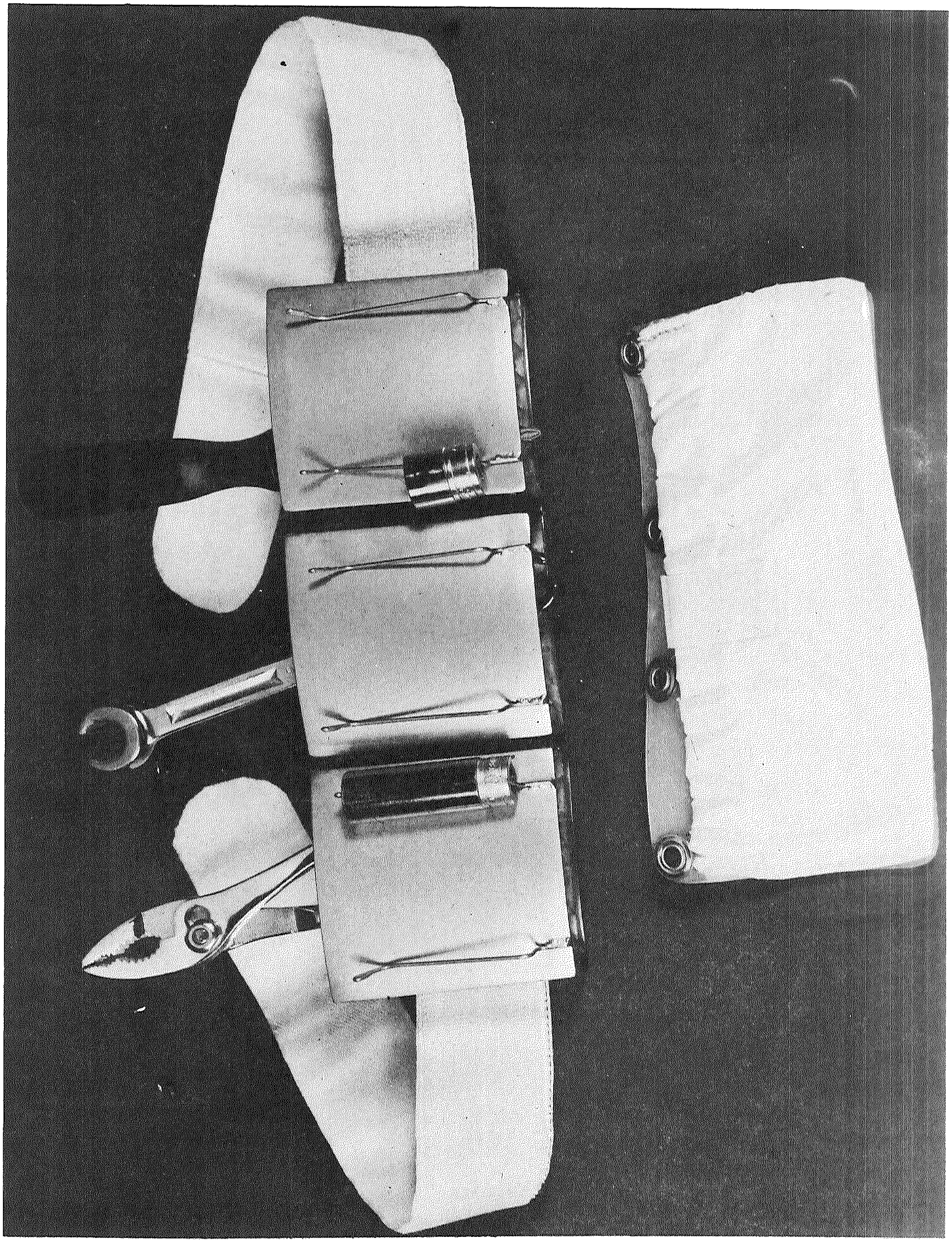


Figure III-6 Parts Carrier

Table III-1 Tools and Equipment

TOOL DESCRIPTION	QUANTITY	TOTAL ESTIMATED WEIGHT AND VOLUME
Sockets and Drives		
Socket, Deep, 3/8-in. Double Hexagon 3/8-in. Square Drive	1	1.8 oz. 3.0 cu. in.
Socket, Deep 7/16-in. Double Hexagon 3/8-in. Square Drive	1	1.8 oz. 3.5 cu. in.
Socket, Deep, 1/2-in. Double Hexagon 3/8 in. Square Drive	1	1.8 oz. 3.5 cu. in.
Socket, Deep, 9/16-in. Double Hexagon 3/8-in. Square Drive	1	2.2 oz. 3.5 cu. in.
Socket, Standard 1/4-in. Double Square 3/8-in. Square Drive	1	.75 oz. 1.0 cu. in.
Socket, Standard 3/8-in. Double Hexagon 3/8-in. Square Drive	1	.75 oz. 1.0 cu. in.
Socket, Standard 7/16-in. Double Hexagon 3/8-in. Square Drive	1	1.0 oz. 1.0 cu. in.
Socket, Standard 1/2-in. Double Hexagon 3/8-in. Square Drive	1	1.0 oz. 1.0 cu. in.
Socket, Standard 9/16-in. Double Hexagon 3/8-in. Square Drive	1	1.0 oz. 1.0 cu. in.
Socket, Standard 5/8-in. Double Hexagon 3/8-in Square Drive	1	1.0 oz. 1.0 cu. in.

Table III-1 Tools and Equipment (Continued)

TOOL DESCRIPTION	QUANTITY	TOTAL ESTIMATED WEIGHT AND VOLUME
Socket, Standard 11/16-in. Double Hexagon 3/8-in. Square Drive	1	1.0 oz. 1.0 cu. in.
Screw Driver Bit Square Head, 5/32-in. Shank Length, 2-in. 3/8-in. Square Drive	1	1.3 oz. 0.75 cu. in.
Screw Driver Bit, Std. Tip Blade 3/8-in. by 1/16-in. Length, 3-1/2-in. 3/8-in. Square Drive	1	2.0 oz. 1.55 cu. in.
Screw Driver Bit Hexagon, 1/16-in Shank Length, 1-in. 3/8-in. Square Drive	1	1.3 oz. 1.55 cu. in.
Screw Driver Bit Hexagon, 5/64-in. Shank Length, 1-in. 3/8-in. Square Drive	1	1.3 oz. 1.55 cu. in.
Screw Driver Bit Hexagon, 3/32-in. Shank Length, 1-in. 3/8-in. Square Drive	1	1.3 oz. 1.5 cu. in.
Screw Driver Bit Hexagon, 1/8-in. Shank Length, 1-in. 3/8-in. Square Drive	1	1.3 oz. 1.0 cu. in.
Screw Driver Bit Hexagon, 5/32-in. Shank Length, 1-in. 3/8-in. Square Drive	1	1.3 oz. 1.0 cu. in.

Table III-1 Tools and Equipment (Continued)

TOOL DESCRIPTION	QUANTITY	TOTAL ESTIMATED WEIGHT AND VOLUME
Screw Driver Bit Hexagon, 3/16-in. Shank Length, 1-in. 3/8-in. Square Drive	1	1.4 oz. 1.0 cu. in.
Screw Driver Bit Hexagon, 1/4-in. Shank Length, 1-in. 3/8-in. Square Drive	1	1.4 oz. 1.0 cu. in.
Screw Driver Bit Hi-Torque No. 1 3/8-in. Squire Drive	1	0.8 oz. 0.58 cu. in.
Screw Driver Bit Hi-Torque No. 2 3/8-in. Square Drive	1	1.4 oz. 1.3 cu. in.
Extension Bar, 12-in. 3/8-in. Square Drive	1	8.0 oz. 3.0 cu. in.
Extension Bar, 8-in. 3/8-in. Square Drive	1	4.0 oz. 2.5 cu. in.
Extension Bar, 4-in. 3/8-in. Square Drive	1	3.5 oz.
Handle, Ratchet, Reversing 30 Tooth, 3/8-in. Square Drive Length, Max. 8 in.	1	9.5 oz. 8.0 cu. in.
Handle, Ratchet Head, Torque-Limiting, 5 to 150 in. lbs. 3/8-in. Square Drive Length, Max. 10 in.	1	9.0 oz. 7.0 cu. in.
Universal Joint 3/8-in. Square Drive	1	2.5 oz. 1.0 cu. in.

Table III-1 Tools and Equipment (Continued)

TOOL DESCRIPTION	QUANTITY	TOTAL ESTIMATED WEIGHT AND VOLUME
Screw Drivers, Wrenches, and Pliers		
Screw Driver Standard Tip 3/16-in. Width 4-in. Blade Length	1	1.38 oz. 4.50 cu. in.
Screw Driver Standard Tip 1/4-in. Width 4-in. Blade length	1	1.4 oz. 4.6 cu. in.
Screw Driver Phillips, No. 2 4-in. Blade Length	1	1.4 oz. 4.5 cu. in.
Wrench, Open End/Box 5/16-in., Length, Max. 6 in.	1	2.5 oz. 1.7 cu. in.
Wrench, Double End, Flare Nut 3/8 X 7/16-in. Length, Max. 6-1/2-in.	1	1.0 oz. 2.40 cu. in.
Wrench, Double End, Flare Nut 1/2 X 9/16-in. Length, Max 8-in.	1	1.0 oz. 2.44 cu. in.
Wrench, Double End, Flare Nut 5/8 X 11/16-in. Length, Max. 9-in.	1	1.0 oz. 2.47 cu. in.
Wrench, Adjustable 10 in.	1	9.0 oz. 10.0 cu. in.
Pliers, Channel Lock Type	1	12.0 oz. 9.0 cu. in.
Pliers, Needle, Pin Gripping Nose	1	2.0 oz. 7.5 cu. in.

Table III-1 Tools and Equipment (Continued)

TOOL DESCRIPTION	QUANTITY	TOTAL ESTIMATED WEIGHT AND VOLUME
Pliers, Connector, Electrical, 10 in.	1	4.0 oz. 9.5 cu. in.
Pliers, Common, 8 in., Slip Joint	1	4.0 oz. 9.5 cu. in.
Cutter, Diagonal Pliers	1	6.0 oz. 4.0 cu. in.
Vise Grip, 7 in.	1	10.0 oz. 11.5 cu. in.
Wire Stripper, Crimper	1	12.0 oz. 10.0 cu. in.
Miscellaneous Tools		
Pin Straightener	1	4.0 oz. 10.0 cu. in.
Vise, Bench, 2 in. Jaws Vacuum Base Type	1	32.0 oz. 64.0 cu. in.
Clamp, 4 in. "C" Type	1	8.0 oz. 8.0 cu. in.
Multimeter, Portable, 20,000 ohms/volt DC 50,000 ohms/volt AC	1	56.0 oz. 110.0 cu. in.
Mirror, Inspection Length, Max. 12 in.	1	3.0 oz. 3.5 cu. in.
Mechanical Finger, Flexible; Length, Max. 17 in.	1	3.0 oz. 3.5 cu. in.
Scissors	1	6.0 oz. 4.0 cu. in.
Hammer, Ball Peen, 16 oz.	1	9.0 oz. 22.0 cu. in.

Table III-1 Tools and Equipment (Continued)

TOOL DESCRIPTION	QUANTITY	TOTAL ESTIMATED WEIGHT AND VOLUME
O-Ring Extractor	1	4.0 oz. 6.0 cu. in.
Punch, Long Taper End Dia. 3/32 in. Max. Length 11-1/2 in.	1	2.0 oz. 1.0 cu. in.
Flashlight, Rechargeable	1	8.0 oz. 9.0 cu. in.
Tape Measure, 10 Feet	1	2.0 oz. 0.5 cu. in.
Inserter/Removal Contact Tool, No. 12 Gauge Wire	3	1.5 oz. 2.0 cu. in.
Inserter/Removal Contact Tool, No. 16 Gauge Wire	3	1.5 oz. 2.0 cu. in.
Inserter/Removal Contact Tool, No. 20 Gauge Wire	3	1.5 oz. 2.0 cu. in.
Miscellaneous Support Equipment		
Spares Translation Carrier	1	10 oz. 36 cu. in.
Translation Kit Tether	1	3 oz. 20 cu. in.
Task Procedures 6 x 8-in.	TBD	TBD
Small Parts Retention Device	1	2.0 oz. 10 cu. in.
Tool Carrier	2	41 oz. 122 cu. in.

Table III-1 Tools and Equipment (Concluded)

TOOL DESCRIPTION	QUANTITY	TOTAL ESTIMATED WEIGHT AND VOLUME
Leak Repair Kit Liquid Subsystems	1	18.0 oz. 48 cu. in.
Flexible Retention Device	1	3.0 oz. 5.0 cu. in.

Table III-2 Consumables

ITEM DESCRIPTION	QUANTITY	TOTAL ESTIMATED WEIGHT AND VOLUME	USAGE ENVIRONMENT
Wire, Safety .032 dia.	100 ft.	4.0 oz. 2.0 cu. in.	Shirtsleeve
Tape, Pressure Sensitive, 2-in. Width	50 yds.	6.0 oz. 24.0 cu. in.	Shirtsleeve
Tape, Pressure Sensitive, 3/4-in. Width	50 yds.	3.0 oz. 9.0 cu. in.	Shirtsleeve
Electrical Tie Cord Viton Lacing Tape	200 ft.	1.5 oz. 3.5 cu. in.	Shirtsleeve
Wire, Electrical, Stranded, No. 20 Insulated	50 ft.	3.0 oz. 1.5 cu. in.	Shirtsleeve
Wire, Electrical, Stranded, No. 16, Insulated	50 ft.	8.0 oz. 3.0 cu. in.	Shirtsleeve
Wire, Electrical, Stranded, No. 12 Insulated	50 ft.	20.0 oz. 8.0 cu. in.	Shirtsleeve
Terminals, Wire, End and Splice, Misc. Size & Type	TBD	2.0 oz. 4.0 cu. in.	Shirtsleeve
Velcro Strips, Pile, 1-in. Width	180 in.	2.0 oz. 7.5 cu. in.	Shirtsleeve
Velcro, Strips, Hook, 1-in. Width	180 in.	2.0 oz. 7.5 cu. in.	Shirtsleeve
Tape, Pressure Sensitive, 1-1/2-in. Width Red (unserviceable condition tags)	50 yds.	6.0 oz. 12.0 cu. in.	Shirtsleeve
Rag, General Purpose	12 x 12-in.	2.0 oz. 13.5 cu. in.	Shirtsleeve

IV. FLUID REMOVAL TOOL

For any future inflight maintenance plans being developed for long-duration missions, the capability must exist to repair fluid subsystems. Before a fluid component or system can be replaced or repaired, the fluid within the system, in the area of the repair section, must first be removed or contained. After component replacement, the system must be recharged and bled-in to remove trapped air.

As part of this contract, a unique fluid removal tool was conceived, developed, and a prototype fabricated. This fluid removal tool performs all of the operations required for fluid system maintenance; (1) fluid removal, (2) intermediate storage of the fluid that was removed, and (3) fluid refill of the system after repair. The tool is hand operated and uses the mechanical fittings, that are a part of the system, as the point of fluid removal.

It is felt that this concept provides a significant advance in new technology, and that this concept can be used for other applications. The unique features of this tool are:

1) The tool is simple in design with inherently high reliability;

2) It requires no additional interfaces (power, fluid storage tanks, nitrogen purges, etc.) for operation;

3) The procedure is straight-forward and should not require extensive astronaut training;

4) No special equipment or hardware is required in the fluid system at the point of fluid removal (such as valves, test ports, disconnects, etc.);

5) The tool can be used in either a one-g, partial-g, or zero-g environment;

6) It can be used for non-toxic fluids.

A. PRINCIPLE OF OPERATION

The principle of operation is based upon controlled leakage past the seal of a mechanical fitting. The fluid removal concept is shown in Figure IV-1 which describes a typical mechanical fitting with a fluid collection clamp attached next to the fitting. To remove the fluid, the collection clamp is attached next to the fitting. The fitting "nut" is loosened, (one-half turn is ample) which allows leakage of the fluid past the seal, between the tubing and the fitting nut, and into the collection cavity. A negative differential pressure applied at the clamp provides the driving force necessary to establish the leak and direct the flow of liquid into the collection chamber, and then to a storage bag. The low durometer seals provide a seal at the face of the fitting nut and on the tube to form a chamber, thus preventing leakage of air into the chamber and containing the liquid.

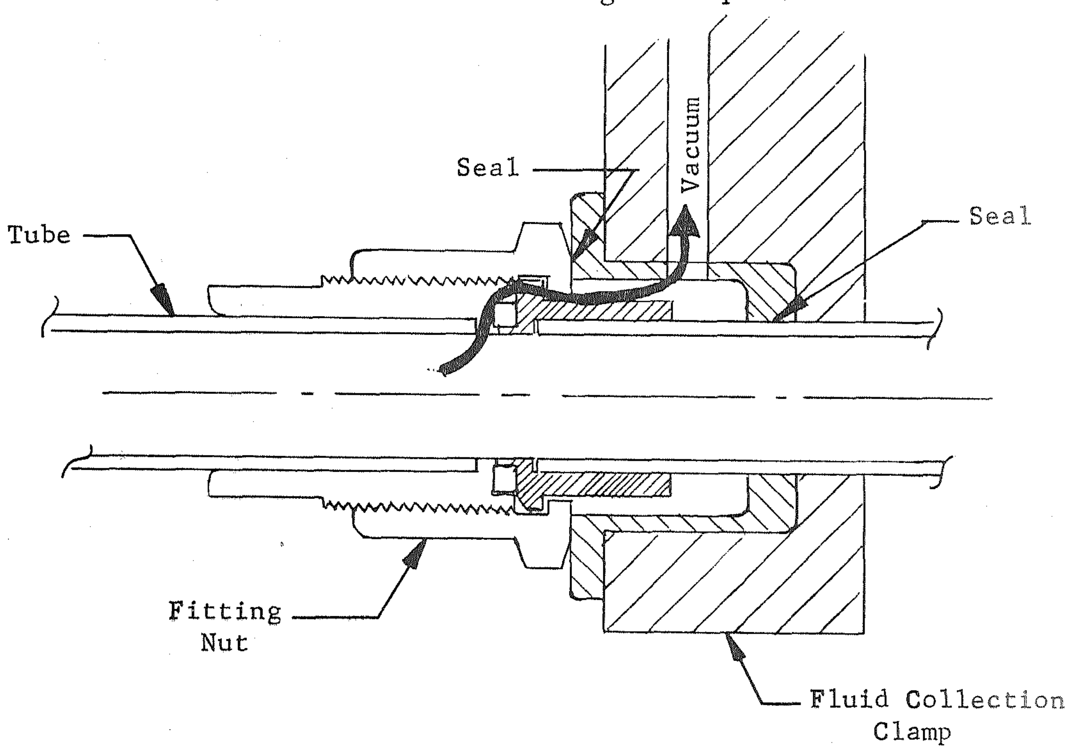


Figure IV-1 Fluid Removal Concept

The back side of the clamp provides a "clamping" action, or metal-to-metal fit on the tube, that serves two purposes; (1) to align the seals on the tube and fitting nut; and (2) to anchor the clamp to the tube. The clamp must be anchored to the tube so that when the fitting nut is backed off, it will compress the face seal, and separate the fitting "seal" and the threads to establish the leak path.

The total concept encompasses the removal of fluid from the system, intermediate storage of the fluid, and refill of the system after a repair is accomplished. Figure IV-2 shows a schematic of the total removal system. In Figure IV-2, the hand pump withdrawal device would be clamped to fitting "B". Fitting "A" and "B" would then be backed off allowing fluid to be removed (by suction) from the system at fitting "B", into the hand pump, and from there to the storage container.

After the fluid system repair is accomplished, the inlet valve is closed and the fill valve is opened to direct fluid back into the system. The flexible storage container also acts as a manual fluid pump and a liquid/gas phase separator. The hydrophobic screen on the storage bag will allow vapor or air to pass through the screen but will not allow liquid to escape; thus the screen acts as a vent and a phase separator. The flexible container, with the fluid in it, can be rolled up like a toothpaste tube or slowly squeezed to push the vapor or air out the hydrophobic screen to separate the gas from the liquid. After the gas is separated out, the hydrophobic screen fitting is capped and the container is either squeezed or rolled up, thus forcing the liquid back into the fluid system. The fluid boundary interface, entering the dry system, will push the gas left in the tube out through fitting "A", thus completing the cycle.

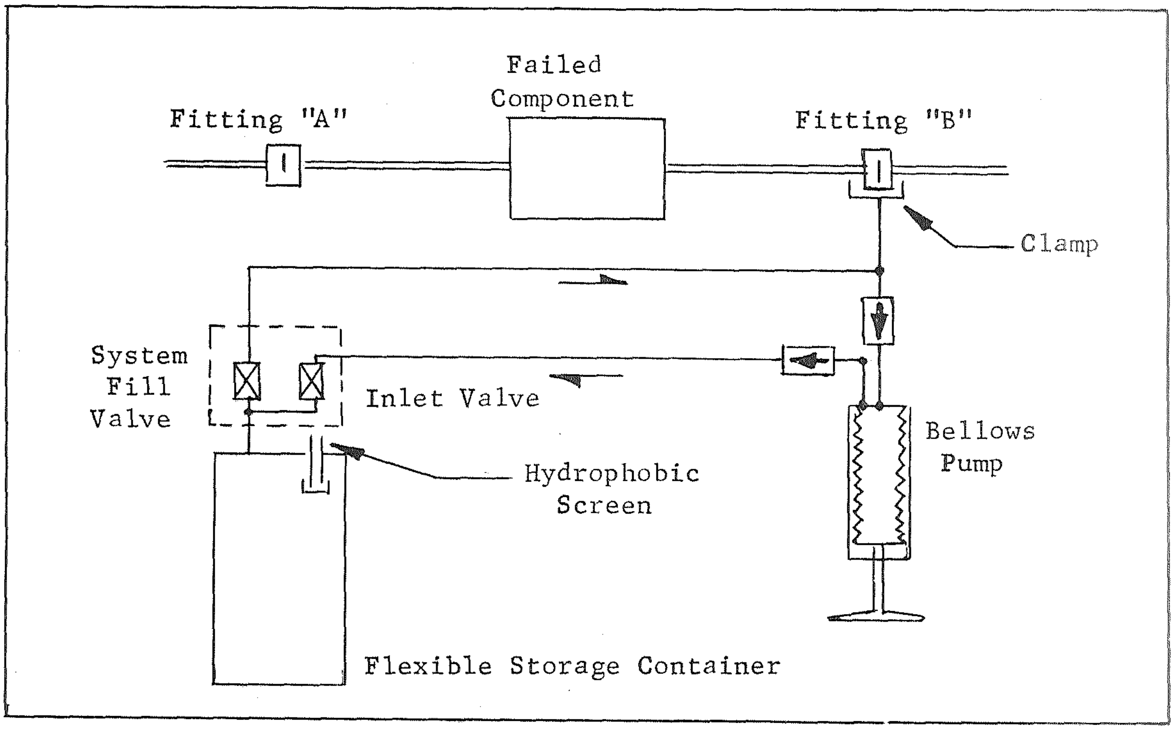


Figure IV-2 Fluid Removal Tool Schematic

B. FLUID REMOVAL TOOL DESIGN

The four basic items that form the fluid removal tool assembly, Figure IV-3, are the:

1) Fluid Collection Clamp;

2) Fluid Removal Pump;

3) Hose and Valve Assembly;

4) Flexible Storage Bag.

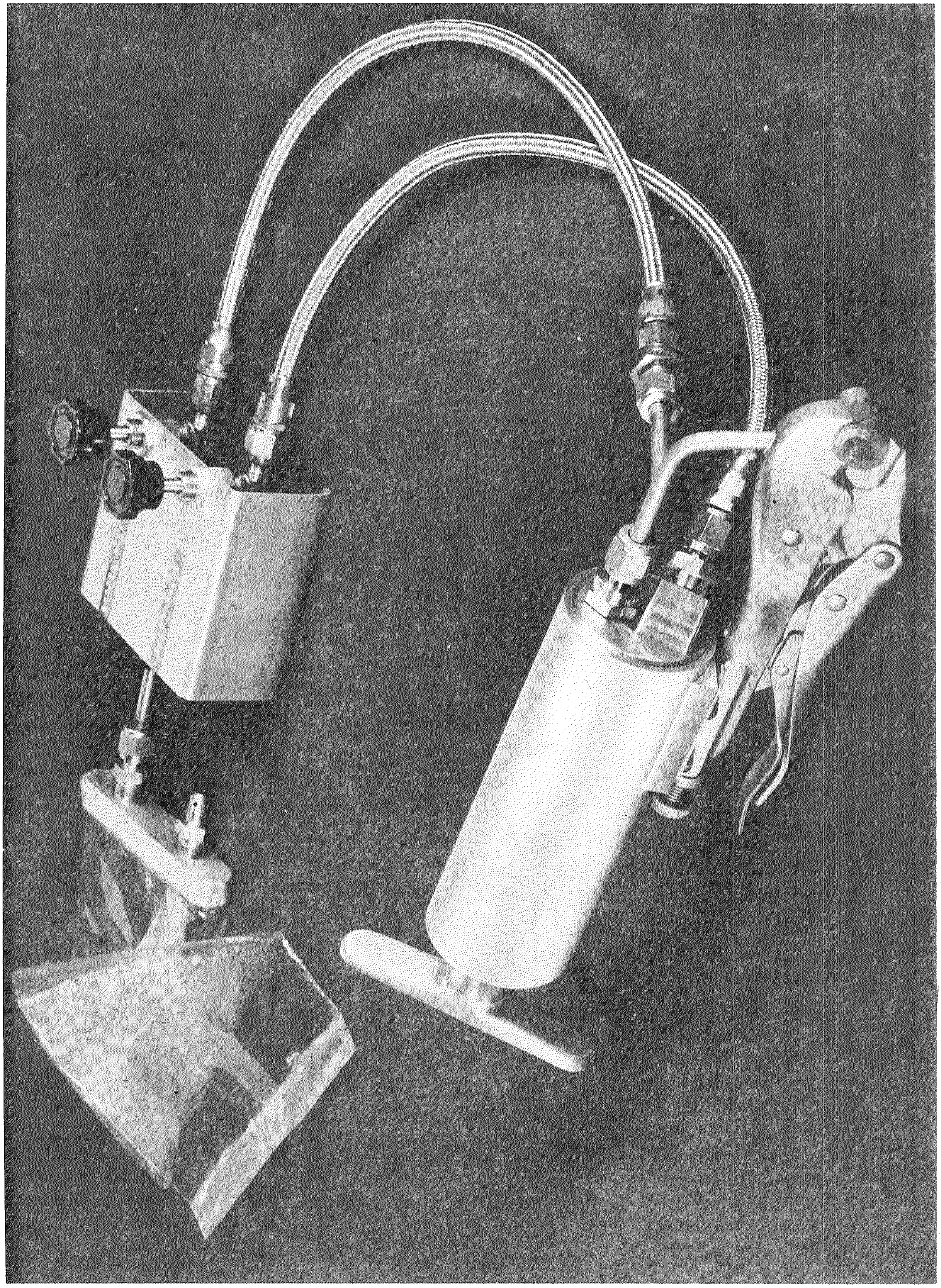


Figure IV-3 Fluid Removal Tool Assembly

The purpose of the fluid collection clamp is to position or anchor the assembly onto the tubing, and to provide a sealed cavity around the fitting. The clamp is a vise grip that has been modified for the cavity and seal, with an attachment that fastens the clamp to the pump and forms one assembly. The seal material is MMS-138 silicone rubber that has been fabricated by a mold pour technique. During development tests it was found that a soft seal conformed easier and sealed better at the lower differential pressure (less than 2 psi) incurred during this process. The silicone rubber has a hardness of approximately grade 35 durometer.

The cavity was designed to fully enclose the seal, minimize the void volume, and provide a flow path to the pump. The seal is bonded to the cavity, first using a Dow Corning A-4014 primer prior to application of a thin film of MMS-138 silicone adhesive. The flange portion of the seal is of sufficient size to be used on most 1/4-inch fittings.

Since this was a prototype unit, the clamp was only sized for 1/4-inch tubes and fittings, which are the most common in spacecraft fluid systems. Future designs could include different sized seal "blocks" that could easily slide into a groove in the hand clamp, thus making the tool adaptable to various tube sizes.

The fluid removal pump design is based upon a metal bellows with an inlet and outlet check valve configuration. The unit is fully enclosed and all of the parts that come in contact with the fluid are stainless steel. It should be mentioned that within the total assembly, the fluid surfaces are stainless steel, teflon, and silicone rubber. These materials are space compatible, and also are compatible with most or all of the spacecraft fluids.

The pump is operated by a hand pumping action and has the capacity to displace 3.38 cubic inches per stroke. The force required to actuate the pump is very low. The pump handle is free to rotate on the shaft so that no torques will be imparted to the bellows assembly. The handle has a detent that will allow the pump bellows to be locked in the compressed position. This lock feature allows the astronaut to apply the clamp to the fitting, release the lock, and thus have an initial pumping action caused by the release of the bellows, as the astronaut is loosening the fittings. This feature insures no external leakage from the fitting, and also provides an indication that controlled leakage or fluid flow has started, thereby an indirect indication that the fitting has been backed off sufficiently. The pump can be easily assembled and disassembled and has a minimum of parts.

The hose and valve assembly is comprised of an inlet and outlet hose, each 18 inches long, and two hand-operated shutoff valves mounted on a hand-held panel. The 1/4-inch diameter hoses are steel braided with a teflon inner liner. Each hose has a different end fitting so that they will not be inadvertantly interchanged on the pump fittings. All tubing and fittings are also 1/4 inch. The position of the valves on the hand-held panel are appropriately marked to enable easy operation by the astronaut.

The flexible storage container is constructed from 3 mill etched teflon bonded to an aluminum fitting block. The teflon is clear so that the astronaut can see the contents of the container. The teflon film has a high percentage of elongation and high strength properties so that is is structurally adequate for its intended purpose. The container was sized for 1500 milliliters, which should be sufficient for the repair and removal of individual components or modules from a fluid system. The 1500 milliliter volume is equivalent to that volume contained in 300 feet of 1/4-inch tube.

The teflon hydrophobic screen is bonded to the vent fitting and can be removed from the flexible container. The effectiveness of a hydrophobic screen is dependent upon the surface tension contact angle of the fluid and the head of the fluid. The latter is not a constraint in zero-g if the flexible container is not squeezed too rapidly. Tests were conducted with tap water, which is effective with this screen. Different screens with different materials and screen sizes are available and can be used for different fluids. It is recommended that further work on this tool should include zero-g tests with other fluids.

V. LEAK SEAL REPAIR KIT

The ability to repair minor system malfunctions in future manned orbiting spacecraft is vital because of the extended service life required for such systems. One problem which must be dealt with is a leak in a component or fitting in any of the spacecraft fluid systems. The leaks to be considered are large enough to be detected through casual observation, but not large enough to require immediate or emergency replacement of the component or fitting.

This discussion presents an analysis of various methods which might be employed to seal water system leaks, and discusses the procedures and techniques required to effect a seal under varying conditions. Criteria specifying the types of sealant used and the limiting parameters that must be considered are also presented.

For this program, water-based systems were selected for the baseline fluid because they represent 80 percent of the fluid systems that will be used on the Space Station. Table V-1 lists all of the gaseous and liquid systems for the Space Station. It should be noted that all of the subsystems within the Water Management, Waste Management, and Thermal Control systems are water-based systems. Even though the objective of this program was to seal leaks in water-based systems, indirectly the tests were also conclusive for nitrogen since the test program also included a leak check using nitrogen as the pressurizing gas.

A total of 24 different sealing techniques, and combinations of several techniques, were considered. Many were dropped from consideration because of obvious disadvantages. Preliminary testing was performed on the remaining candidate techniques and a complete series of tests was conducted using the procedures and materials finally chosen as being best suited for the existing conditions.

Table V-1 Space Station Fluid Systems

SYSTEM	FLUID	OPERATING PRESSURE (psi)	TOXIC
1. Environmental Control System			
Atmosphere	Oxygen & Nitrogen	10 or 14.7	No
	Carbon Dioxide	4 mm Hg	Yes
Recovery System	Methane		Yes
2. Water Management			
Personnel	Potable Water	30	No
Recovery	Urine	30	No
	Wash Water	30	No
	Flush Water	30	No
	Condensate	30	No
	Shower Water	30	No
3. Waste Management	Urine	30	No
	Feces	--	No
4. Thermal Control			
Cabin Control	Water	140	No
Radiator	Freon-21	160	No
5. Propulsion			
Maneuvering, fuel	Hydrazine	300	Yes
pressurant	Nitrogen or Helium	3600	No
Orbit Keeping, fuel	Methane	30	Yes

In this program it was concluded that the simplest and most adaptable method of sealing leaks was a process using anaerobic adhesive followed by overwraps of self-vulcanizing silicone tape and pressure sensitive teflon tape. To promote curing of the anaerobic sealant, a primer (MIL-S-22473C1) is applied to the metal surface prior to application of the adhesive.

These materials and methods were selected for several reasons. First, no special tools are required; thus, cost and weight penalties are minimal. Second, little or no special training is necessary because the procedures to be followed are straightforward. Third, the actual sealing procedure can be performed in less than five minutes. Finally, the methods employed are most applicable to most situations; that is, the techniques used are capable of sealing more and different kinds of leaks than any other single system or approach.

The majority of the tests, and also the best results, were obtained on the repair of leaks in tubes and at tube fittings. Although the results of the testing on valves and tanks were not as spectacular, the methods show some promise. It is believed that more testing and further improvement in technique would have ultimately resulted in a successful leak sealing method on valves and tanks.

A. DEVELOPMENT GUIDELINES

One of the first tasks of this program was to establish guidelines for use in the development of a leak repair technique. The following guidelines are the result of this effort.

1) The objective of the leak seal kit will be to quickly, easily, safely seal fluid leaks.

2) The study shall determine suitable materials for leak seal application suitable to systems on the Skylab, Space Station, and Space Shuttle.

3) The leak seal repair will be used under IVA conditions only, with 90% of the operations performed in shirtsleeve and 10% in a pressurized IVA space suit.

4) The device shall be developed for zero-gravity use and demonstration (rather than one-g).

5) Leak-sealant compounds suitable for use with fluid propellants will be studied, but will not be developed due to the relevant compatibility problems.

6) Compounds suitable for use with potable water subsystems will satisfy contract intent.

7) It shall be a design goal to seal the system while the system is in operation with full system pressure.

8) A leak shall be defined as a wetted surface or a dripping-type leak. Rupture of a line or tank need not be considered.

9) Leaks shall be assumed to occur at the following points, and as a design goal, the leak seal applicator(s) shall be designed to correct the following leaks:

   a. at tube fittings;

   b. component exterior (fitting, stem leak, or external thread);

   c. tank leak on the tank exterior.

10) The sealant material shall be compatible with the Skylab and Space Station atmospheres, and shall meet the applicable oxygen safety and gas-off compatibility requirements.

	Cabin Pressure	Mixture Ratio Nitrogen/Oxygen	Humidity	Temperature Range
Skylab	5.0 ± 0.2 psia	26/74	50 ± 10 RH 45°F Minimum D. P. 95% Maximum RH	70 ±5°F
Space Station	10-14.7 psia	78/21	45°F-85°F Dewpoint	65-85°F

11) The sealant shall have a rapid cure time with a design goal of 30 minutes.

12) The materials study shall consider the following fluids, systems pressures, and chemical compatibility in the following order of priority.

System	Fluid	System Pressure
Potable Water	Water	30 psig
Cabin Thermal Control	Water	140 psig
Waste Management	Water, Urine, Wash Water, Flush Water, Condensate	0-30 psig
Thermal Control	Coolnol-15	200 psig
Thermal Control	Methanol-Water	50 psig
Thermal Control	Freon-21	140 psig
Thermal Control	Ethylene Glycol-Water	60 psig
Propulsion	Hydrazine	300 psig
Propulsion	Nitrogen Tetroxide	300 psig
Propulsion	Monomethylhydrazine	300 psig

B. CANDIDATE SEALING TECHNIQUES

The following is a summary of the sealing techniques investigated, with advantages and disadvantages cited where possible. As can be seen, many of the techniques could be rejected immediately as being difficult or impossible to accomplish in a Space Station environment. All techniques, however, were given some consideration.

1. Tape Wrapping of Leak Area

Tape wrapping can be accomplished on tubing easily; fittings are a little more difficult depending where the fitting is located in the system. If the fitting is accessible, it should be no more difficult than the tubing itself. If close to a component or tank, the task can be slightly difficult to practically impossible depending if the leak lies on the tubing side of the tank or component side of the fitting. This difficulty, of course, is dependent upon the geometry of the component. This can be overcome somewhat by having a very conforming tape - elastomeric in nature - or at least deformable, to the extent of fitting compound curves or boss-like protrusions. Tape wrapping approaches are summarized as follows:

a. Self-Vulcanizing Elastomeric Tape - Self-vulcanizing tapes are elastomeric (rubber-like) materials in tape form, of variable thicknesses and widths, which upon intimate contact with themselves vulcanize into a solid mass. The ability to adhere to a surface other than themselves is somewhat problematical. One redeeming feature is that the tape can be pulled snugly against convex surfaces. If the tape itself will not adhere to other surfaces, the surface can be primed with another material to secure sufficient bonding strength, or a quick-curing adhesive interface may be spread under the first layer of tape against the metal surface. This adhesive will, of course, have to bond to the metal and also the self-vulcanizing over-wrap of tape. The adhesive could be pressure-sensitive, cyanoacrylate, or micro-encapsulated epoxy; however, no solvent containing adhesive is permissible because of the adverse effects on the cabin atmosphere and also on the self-vulcanizing tape. Some of the self-vulcanizing tapes can only be used as an interim measure, or at best as an internal layer of a permanent fix, because of probable out-gassing. This problem may be circumvented by covering the tape layer with a non-permeable and non-out-gassing covering such as a pressure sensitive aluminum foil tape, sealed clam-shell, or plastic coating. Some self-vulcanizing tapes are compatible with the cabin atmosphere.

b. Pressure Sensitive Adhesive Coated (or Impregnated) Conforming Tape - This tape can be used in much the same manner as the elastomeric self-vulcanizing tape. However, the tape itself is structurally different. The tape body would have to be constructed in such a manner that it would, when applied, conform to an undulating substrate. This can be done by making the tape body of woven fabric, braided fabric, or an extensible material (elastomeric or rubber-like). The tape body could be coated or, in the case of woven or braided fabric, it could be impregnated with a pressure sensitive adhesive. The extensible nature of the tape would let it conform to the shape being wrapped and the pressure-sensitive adhesive would bond it in place and eliminate porosity and/or permeability. The problem of out-gassing in this system could be overcome by the same means as cited for self-vulcanizing tapes.

c. Micro-encapsulated Adhesive Coated Tape - This tape is similar to the self-vulcanizing and pressure sensitive tapes described in paragraphs a and b; however, the adhesive mechanics would be different. Activation of a micro-encapsulated adhesive tape requires the application of either pressure or heat. Although pressure would occur while wrapping, it would not be sufficiently uniform to ensure that all the adhesive would be activated. Some independent means of pressure application would have to be utilized such as a vacuum or pressure bag or a clam-shell with pressure pads, or by application of heat which could be accomplished with a heat blanket on the tape.

The adhesive would have to be of a thermo-setting type to exclude any change of solvent and/or undesirable reaction product release into the cabin atmosphere.

d. Heat-Shrinkable Tape - Heat-shrinkable tapes are similar to those described in paragraphs a, b, and c and can be used in much the same manner. After being wrapped they require the addition of heat. The heat causes the tape to shrink in the longitudinal direction and ensure a very tight wrap. The tape could be made in such a manner as to be two distinct layers. The bottom layer would be of a low melting point (150-350°F) polymer which would fuse upon heat application and produce a continuous, coherent mass. The right choice of fusable layer would wet the overwrapped surface as well as the outer-most tape layer and bond them together. This could very well produce a patch of very low permeability that would resist high pressure.

Several different polymer types are available in the heat-shrinkable form; however, the fusable layer concept may require investigation or even development to ensure a proper system.

2. Mechanically Held or Bonded Patches

This type of repair would not be applicable to highly irregular surfaces nor ones with small uneven radii (conical), because of the difficulty of tightly conforming to the substrate. Bonded patches would be more likely to conform because of the fluid nature of the bonding material before permanent set takes place; however, irregular surfaces would still be very awkward. It would be prohibitive to design special patches for each possible leak area; however, the patch approach has possibilities in the realm of tank domes and walls, or component sides where gently rounded surfaces are present.

a. Self-Vulcanizing Elastomer - This scheme would have to be used with an overlay of plastic or metal because of outgassing effects. The metal could be foil or thin sheet to promote deformation and conformance to the substrate. If the elastomer would not bond to the substrate or metal overlay by itself, adhesion could be promoted by a primer, or adhesive inter-layer. The principle advantage of using the self-vulcanizing elastomer is the inherent ability of the material to be built up into any desired thickness and variations of thicknesses in the same patch that ultimately becomes (after vulcanizing) a homogeneous mass. The patch could be held in place by mechanical means such as a clam-shell clamp, hose clamp, or other means, to apply a compressive load sufficient to offset leak pressure and effect a seal.

b. Pressure-Sensitive Adhesive - This method could seal in gently rounded substrate areas. It has a low order of strength and would not be satisfactory for high pressure leaks. This material would have to be used with an overlay of plastic or metal sheet stock in order to take loads of any magnitude, since it never cures to a solid mass, but remains as a very tacky semi-solid or highly viscous liquid.

c. Thermo-Plastic Adhesive - This system would require a heat application technique, such as a stud-bonding gun. Highly irregular surfaces would not lend themselves to be repaired. Gently rounded surfaces such as tank domes or barrel sections could be repaired quickly, easily, and with a high degree of reliability. The adhesive would be applied to the metallic or plastic patch and would be an integral part of it. The adhesive upon application would be completely "set" when cooled back to room temperature. One drawback would be the requirement of a high heat-flux applicator, since the tank contents would be a large capacity heat sink with a high rate of thermal conductivity.

A possible variation of this would be to use a heated-gun applicator and extrude a molten bead of the adhesive, much as in welding or soldering.

d. <u>Thermo-Setting Adhesive</u> - These materials from a practical standpoint could not be used in a weighed two component system; however, the components could be preweighted and packaged and mixed within the packaging container such as a "Semco Cartridge". The container could very well act as a dispensing device also. Even so, the cure time of the material would be relatively long unless heat was applied. The less complicated method would be to use a "B-staged" adhesive or one of the paste types with the hardener dispersed within the matrix but not soluble in it below some elevated temperature. The "B-staged" adhesive could be attached to a metal or plastic patch proper and be bonded to the leak surface upon application of heat and pressure. An applicator of the Stud Bonding Gun type would serve as a means of applying heat and pressure. The application of this system could be relatively fast, but high temperatures are required (300-600°F). These temperatures may be difficult to obtain on a tank full of liquid.

e. <u>Anaerobic Adhesives</u> - These are one component systems which cure under the conditions of exclusion of atmospheric oxygen and very intimate faying surface contact. They are extremely fast curing in contact with most surfaces at room temperature. They can be made to cure even faster by application of a primer-catalyst. To obtain a proper cure the adhesive must be squeezed between faying surfaces to produce a very thin and uniformly thick bond-line. This can be done easily on smoothly contoured surfaces, but highly irregular surfaces may present a problem.

f. <u>Inorganic Adhesives</u> - These materials have the major disadvantages of being brittle, of a low order of strength, difficult to use, possibly corrosive to the faying surfaces, and shock sensitive. Some require high curing temperature (400 to 700°F), and others cure at room temperature (chemical substitution). There is a good possibility that they may be too porous to contain leaks unless they are cured by fusion. The major advantages are good chemical compatibility to acids and bases (the same one may not work for both), quick cure, nonflammability, and non-volatility.

These materials are one and two component systems; the one component system usually having water as a solvent with cure depending upon evaporation (slow cure) and the two component system being a chemical substitution reaction with the product being the cured adhesive. These can be somewhat dangerous to handle, because of chemical burns, and possible toxic and/or corrosive volatiles being given off. The most probable choice would be one of the water soluble silicates.

g. Micro-encapsulated Adhesive - These systems are one component systems utilizing a micro-encapsulated hardener and/or resin base. The hardener and resin base are kept completely chemically isolated, although intimately mixed, until heat or pressure or both are applied to rupture the capsules. This rupture initiates the chemical reaction of cure which proceeds to completion.

These systems can be procured in liquid, paste, film, and free-flowing powder forms. This application would undoubtedly require a film form previously applied to a metallic or plastic patch member for simplicity. The hardener-resin base can be specifically chosen to produce an extremely fast cure with 75 to 90% ultimate strength in a matter of minutes. A heated platen-type tool could be used for application. The main draw-back of this system would be the same as for all patch-type repairs: irregular surfaces would be almost impossible to repair.

3. Injection of Sealant into Leak Porosity

The following type materials are best suited to this application:

a) Thermo-elastic

b) Thermo-setting

c) Anaerobic

d) Inorganic (water solution)

The intention of this system would be to actually put some material into the leak passageways and block them internally. To do this the material being injected must be very fluid during the injection period since the leak cross-sectional area will be extremely small. The liquid system being repaired would have to be depressurized to avoid back-pressure on the injected material. The thermo-plastic material (a) would have to be injected under very high pressure and heated to achieve sufficiently low viscosity to penetrate the small leak openings. This could be accomplished with a hand-gun equipped with a heated ram chamber triggered to permit small "shots" of fluid material to be ejected from a nozzle and impinge upon the capillary openings. The nozzle would have to have a guard around it to prevent excessive splatter of material. This apparatus requires a considerable amount of electrical power.

The thermo-setting material (b) might have a sufficiently low viscosity to enter the capillary bore due strictly to capillary attraction; if not, the material could be induced to enter using low pressure in the range of 10-25 psi. Tools of this type were developed by the Martin Marietta Corporation for use on Titan II missiles. It may be practical to use a device such as a hypodermic syringe with the needles modified at the tip to provide conformability and accessibility to the immediate repair area. The thermo-setting mix would not only have to have low viscosity, but also a reasonably long work life. This long work life would require heat application to effect a fast cure on the repair.

The anaerobic adhesive (c) and the inorganic material (d) would be applied in much the same manner as the thermosetting material (b) with a few minor modifications. The anaerobic material should cure quickly (seconds) and completely in capillary bores and if not, a primer-catalyst could be used to promote the cure.

4. Encapsulation

This system's intention is to cover the leak area with a material in the liquid state which, upon curing, produces a solid mechanical block across the channel openings. This will necessitate either extremely good adhesion to the substrate or a continuous enveloping film of material around the system being repaired.

a. Cast - A loosely conforming mold would have to be built around the leak area. A liquid material would then be injected into the mold between the leaking part and the inner surface of the mold, and allowed to cure. The mold would only have to be strong enough to hold the weight of the liquid casting material. Thermo-setting material would probably be the best casting material; however, some thermo-plastic materials could be used. They would have to possess a sharp melting point, i.e., become very fluid at a reasonably low temperature.

b. Molded - The technique in this instance would be somewhat similar to the foregoing, but the mold would have to sufficiently strong to withstand molding pressures in the order of 10-100 psi depending on the molding material viscosity. The higher the viscosity, the higher the molding pressure required and consequently, the stronger the mold would have to be. These two methods would be awkward to use at the very best.

c. Coated - This method would be utilized by applying a coating or film of liquid material to the leak area, and then letting it cure. Molds would not be required. The viscosity of the material must be high, even thixotropic. Thermo-setting materials could be applied by brush or spatula at room temperature and cured at an elevated temperature. Thermoplastic materials could be applied by brush from a hot-melt container and would cure almost instantaneously. Even micro-encapsulated materials could be applied using a spray-gun approach where the gun itself does not throw a fan of material, but uses a small bore aspirator pickup and small orifice nozzle to produce a well-directed stream of material of a small diameter. The impingement velocity would have to be great enough to rupture the microcapsules upon striking the surface to be coated. After coating, the surface can be heated to expedite the cure. Thermo-plastic materials could be sprayed using a hot-pot technique.

d. Stick-Form Coating Application - In this method the coating material would be in a stick or rod form, from all outwage appearances a solid bar. The material itself would have to have the unique property of transferring from the stick to the surface being coated by abrasion or rubbing across the surface. The coating as produced would have to be nonpermeable. The material, to be satisfactory, must shear cohesively from the applicator stick to the substrate, and "reheal" cohesively on the substrate. The coating cannot be layered or sealed but must return to a homogenous mass to preclude porosity. Materials such as waxes, fatty acids, oleoresins, mixtures of shellac, and resins with plasticizers and/or tackifiers could be used.

One other good possibility remains, however. A microencapsulated adhesive could be molded into a bar without rupturing the microcapsules by use of another adhesive which is low strength and friable. When this bar is rubbed across the substrate, the microcapsules would rupture and the low strength adhesive let go, thus transferring a suddenly liquid adhesive to the substrate. This liquid adhesive would wet-out the surface very well and cure quickly. The viscosity of the microencapsulated adhesive could be adjusted to give a very fluid material or one which is somewhat tacky depending upon the particular application need.

5. Combinations of Sealing Systems

The basis of the combination choice must be a system which positively seals but possibly lacks sufficient strength to resist high pressure, will not meet the out-gassing requirements, or is an extreme fire hazard. It is also possible that several of the proposed methods will work equally well; then the approach for selection will be based on the complexity of each system. It seems quite probable that a final solution will be a combination of two or more techniques to fulfill all the physical, chemical, and mechanical property requirements involved. The methods finally adopted will be products of evolution.

6. Plating

The aim of this method is to deposit a thin, coherent, non-porous, metallic coating to a substrate surface completely damming leak openings. The surface to be plated must be bare metal and chemically clean or the plating will not properly adhere. Sufficient thickness would have to be built up to satisfactorily resist the system pressure. The plating would also have to be chemically compatible with the fluid to be contained and must have an affinity for the substrate metal. An aluminum substrate may require two or even more plated layers, of different metals, to be able to obtain a satisfactorily resistant deposit. This is because the metal deposit actually doing the job cannot be plated directly upon aluminum but must have an intermediate layer to establish adhesion.

A bath of the plating solution must be established in contact with the area to be plated. This has to be done regardless of whether the plating is electrolytic or electroless. It is possible that the plating bath would not have to be a fluid/liquid to accomplish its task. The plating bath may also be rendered thixotropic and thus it could be spread on the substrate to be plated. Electroless plating would then take place without any further processing. In the case of electrolytic plating, an anode could be placed in contact with the outer surface of the thixotropic plating bath, lead wires attached to the anode and cathode (substrate), and a DC power source energized to produce the required deposition. Ionic migration of the plating bath should be somewhat slower than normal, but no doubt this could be compensated for by a lower current density and a longer plating time.

The major drawbacks to this method are that the plating is toxic, can cause chemical burns, and because it is an oxidation - reduction reaction will produce gaseous byproducts. Hydrogen will be plated along with the metal ion on the cathode, while oxygen will be plated at the anode and both gases will then be liberated from the plating solution. Application of this process would not be tolerable in a spacecraft situation.

7. Peening

This method is somewhat self-explanatory since peening itself is disruption of the metal surface from impaction, causing a "smearing action" that closes the surface terminated openings. There are two means of applying the peening action. The first is by a stream of metallic particles directed at the surface to be worked; the second by hammer and punch, the punch having a hemispherical point. The hammer and punch could very well be contained in a single unit similar to a "jack-hammer". The shot-peening method would have to be designed in such a manner that rebounding shot would be collected and not allowed to contaminate the surrounding area. A vacuum pick-up device would probably be the most useable and efficient; however, it the shot were steel, a magnetic pick-up might be the best choice.

Any thinning or work-hardening of the metal surface by these methods of peening should not constitute an objectionable hazard, even though some of both will be produced.

Burnishing is included in this section and is a possibility. Burnishing is simply the mechanical movement of the metal surface by the use of a hemispherical, pointed hand tool.

8. Diffusion Bonding

This method depends upon the ability of one metal surface to diffuse into another and intermingle molecularly. Diffusion will not take place unless the contacting surfaces are in intimate contact and have an extreme affinity for one another. The rate of diffusion is dependent upon energy introduced into the system. In normal practice the energy is in the form of heat and/or pressure. A hand vacuum is also used in the process to eliminate atmospheric contamination that occurs in the form of chemical reactions with the metallic interface and/or possible occlusion in the interface.

The major disadvantage in this method is the high energy requirements necessary to accomplish reliable bonding in a short period of time. As an example, an explosive charge can be used to accomplish a bond almost instantaneously. Bonds are produced in titanium at 2000 psi, 1800^{o}F in approximately 3 hours.

This particular method would require extensive evaluation and research to determine if it is feasible.

9. Metallizing (Vacuum or Flame Spraying)

Metallizing on a surface can be produced in either of two ways. The first is by evaporating a metal (such as aluminum) in a vacuum and allowing it to condense on a surface. The second is by injecting a rod or stream of powdered metal into a flame or arc, melting it and directing it upon a surface. Ceramics can also be flame sprayed. In any case, the material acts as if molten and adheres very well to a clean surface. Build-up is relatively easy to accomplish. A hard vacuum source is available and electric power sufficient to heat a resistance element to incandescence in an enclosed volume is the main additional requirement for vacuum metallizing. Flame spraying, on the other hand, requires a hand-gun sprayer with force feeding and either a pressurized gas source or a high amperage electrical source to produce the "flame". Operator skill can be a considerable factor in the flame spraying technique.

10. Welding and Soldering

Fusion arc welding of aluminum, titanium, and stainless steel can be accomplished without using an inert gas shielded arc, and can be accomplished in a vacuum. By the use of a glove-box arrangement, the vacuum could easily be established around the area to be welded, and welding manipulations could be performed through the container sides by extension manipulators. The container could be designed as a clam-shell for lines and small components. Soft deflectable gasketing at the closures would effect a seal. On larger components and tanks the container could be an open-sided box utilizing the same type gasketing. The cabin atmospheric pressure would assist in sealing the vacuum container. Large weld beads are not necessary to accomplish sealing. A very small diameter consumable electrode, of the proper alloy, could be used. This would in fact relieve the problem of supplying high amperage for large diameter welding rods; the resulting welds should be just as chemically compatible as the parent metal.

Soldering would be almost as satisfactory as welding to effect a leak repair. The chemical compatibility, however, would not be as good. The major problem in soldering is to tin the surfaces of aluminum, titanium, and stainless steel. This can be accomplished using the proper soldering flux; however, soldering flux is not compatible in the cabin atmosphere. There is also a method by which these surfaces can be tinned without the use of a flux. Essentially the method consists of using a high rotational speed (10-20,000 rpm) drill motor with a solder loaded soft grinding wheel attached. The wheel by definition is very friable and either has solder particles embedded in the abrasive matrix or the peripherial diameter can be loaded with solder by grinding bar solder. The surface to be tinned is then lightly ground with the solder loaded wheel. This accomplishes two things. The surface is mechanically cleaned and the frictional heat generated is sufficient to melt the solder. The melted solder is spread on the cleaned surface as it melts. This takes place so fast that even active metals such as aluminum do not oxidize before the molten solder wets the surface. Once the metal is tinned, soldering can be accomplished easily. A variation of this method, which would require some development, would be to substitute a fine, close-bristled brush wheel for the grinding wheel. The advantage of this method is that highly irregular surfaces could be tinned.

C. GENERAL TEST FACTORS

Preliminary tests were conducted in the areas of soldering, thermoplastic adhesive, self-vulcanizing tape, and pressure sensitive and anaerobic adhesives. The results of these tests and the pertinent factors regarding other candidate techniques were taken into consideration when choosing the techniques on which more extensive testing would be done.

As a result of this preliminary test phase, it was concluded that the most promising method was a combination system using a liquid anaerobic sealant (Loctite Grade AA) with overwraps of self-vulcanizing and pressure sensitive Teflon (T.F.E. Inc.) tape. In some cases a vacuum seal (General Sealants) adhesive was used in place of the self-vulcanizing tape. To promote curing of the anaerobic sealant, a primer (MIL-S-22473C1) was applied to the test surface beforehand.

Several series of tests were conducted to establish the limiting criteria for leak sealing in the following ranges of temperature and pressure: 33°F to approximately 145°F, and from zero to 150 psig. Leaks were set into several different fittings, tubing and components of various geometrical shapes. Each item was tested separately to determine if the sealing process was adequate in all respects. The leaks resulted from such conditions as a notch in a straight section of tubing or a "damaged" union fitting or valve. Nitrogen gas was used to pressurize the water hydrostatically when required.

The primary objective throughout the tests was to determine the minimum and maximum conditions under which an effective seal could be accomplished. The effects of various system temperatures and pressures were monitored so that limitations, if any, could be established. Successive tests were run with tap water, distilled water, water at 33°F, and water at approximately 145°F. Leak repairs were attempted at system pressures up to 150 psig.

All sealed fittings were subjected to 50, 100, and 150 psig for intervals of five minutes each, and at 150 psig for long duration tests that exceeded 18 hours. If the results of these tests were successful, the fitting was pressurized to 150 psig with nitrogen gas for five minutes and the test section was immersed in a water bath to aid in leak detection.

D. TEST RESULTS

The test apparatus is shown schematically in Figure V-1 below. Stainless steel tubing with a diameter of approximately 1/4-inch was used. An initial system leak check was conducted on the test loop. The water-filled tubing, pressurized to 150 psig, showed no evidence of any leaks after 18 hours.

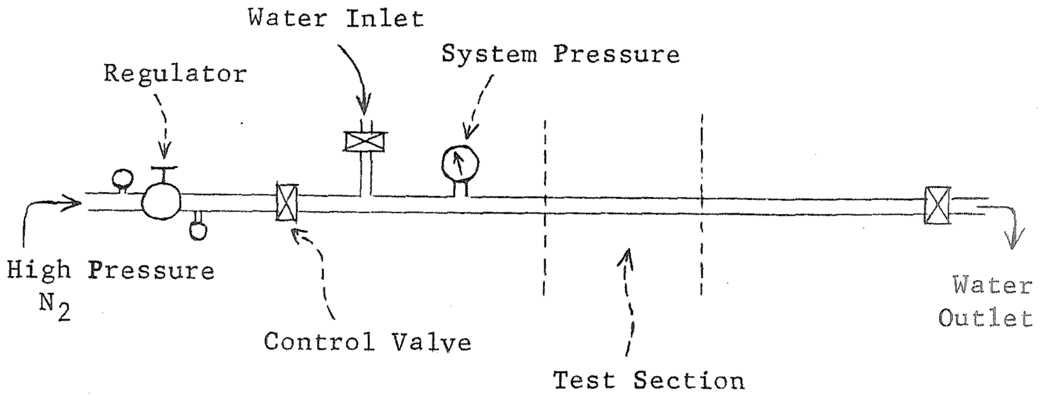


Figure V-1 Systems Test Schematic

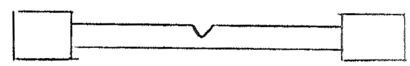
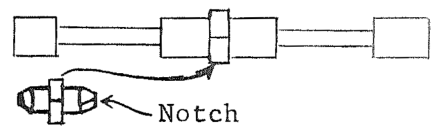
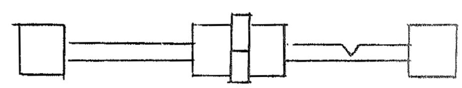
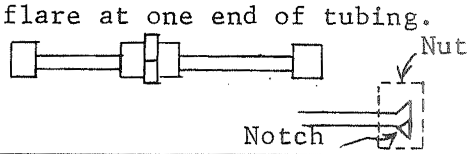
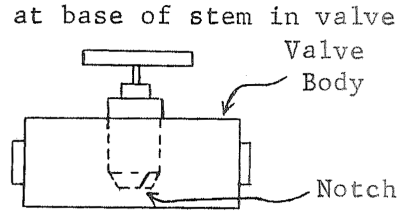
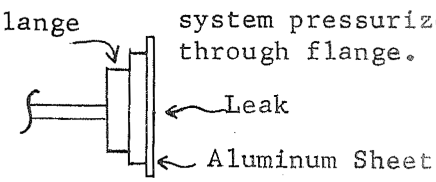
1. Zero Pressure System Tests

The first series of tests was conducted on tubing and fittings which were not pressurized but were wetted before and several times during the sealing process. Tap water was used as the test fluid medium. In general, the sealing procedure included the following steps: (1) the area around the leak was sprayed with Locquic Primer Grade T, (2) after a two or three minute wait to allow the primer to dry, one or two drops of Grade AA Loctite Sealant was placed on the leak area; (3) a layer of self-vulcanizing silicone (permacel) tape was immediately wrapped over and some distance on each side of the leaking area; (4) pressure sensitive teflon tape, which when stretched and wrapped over the fitting tended to pull back on itself thus tightening down on the self-vulcanizing tape and the fitting surface, was then wrapped over the self-vulcanizing tape, and (5) the anaerobic Loctite sealant was allowed a cure time of from two minutes to several hours before pressure testing was begun.

The two wrappings of tape served the purpose of eliminating the air from the vicinity of the anaerobic sealant, allowing it to cure properly. Once the cure was complete, the tape could have been removed without affecting the integrity of the seal. A list of the test sections, or specimens, used is given in Table V-2.

The first test specimen (No. 1) was a seven-inch section of straight 1/4-inch tubing with a notch filed into the tube surface, creating a visible opening. Because it was desired that no sealant be allowed into the interior of the tubing (thus, in a real system, contaminating the system), and because the large opening created would indeed have allowed sealant to seep into the tubing, a preliminary step was taken prior to beginning the sealing procedure. This step was to apply a wrap of self-vulcanizing tape to the tube over the notch before spraying on the primer. This meant, of course, that the seal was accomplished between two layers of self-vulcanizing tape, not between metal and tape as is usually the case.

Table V-2 Fittings and Components Tested

DESIGNATION	DESCRIPTION
Specimen No. 1	Straight section of tubing - notch filed into tube surface. 
Specimen No. 2	Notched union between two sections of tubing. 
Specimen No. 3	Two short sections of tubing - notch filed into surface of one section. 
Specimen No. 4	Two sections of tubing joined by union fitting - notch in flare at one end of tubing. 
Two-Way Hand Valve	Notch at base of stem in valve body. 
Tank (Simulated)	Microporous leak in tank wall- system pressurized through flange. 

The tests on Specimen No. 1 were successful and a summary of the tests performed is given in Table V-3.

Test specimen No. 2 consisted of two short sections of tubing joined by a union, one side of which was notched to form a leak path. A series of tests identical to those performed on Specimen No. 1 was performed on this specimen and the results were also identical (See Table V-3). The normal sealing procedure was followed without the preliminary self-vulcanizing tape wrap. The seal was ultimately formed along the threads of the union on the notched side, as was seen when the fitting was taken apart after testing.

Table V-3 Zero Pressure Systems Test, Specimens No. 1 and 2

CONDITIONS	RESULTS
Sealed Wet @ Zero System Pressure:	Cure Time = 15 Min.
Tap Water @ 50 psig - 5 Min.	No Visible Leak
Tap Water @ 100 psig - 5 Min.	No Visible Leak
Tap Water @ 150 psig - 5 Min.	No Visible Leak
Tap Water @ 150 psig - 18 Hrs.	No Visible Leak
Nitrogen Gas @ 150 psig - 5 Min.	Immersed in Water - No Leak Visible

In both series of tests, the amount of care required to perform the repair was not excessive. In some cases even a relatively careless technique proved sufficient. Little or no previous experience with the materials involved was necessary. Because of the wet surfaces, both tapes had a slight tendency to slip from the grasp, but both adhered well once in place. The actual tape wrapping took approximately two minutes.

A much more difficult leak to seal was produced when a notch was filed into the base of the stem on a valve. The leak thus created was very large, and all initial attempts to effect a seal were unsuccessful. The sealing procedure used on the valve was as follows; (1) Grade T primer was sprayed on where the stem meets the valve body, (2) loctite sealant was applied to the leak area, (3) vacuum bag sealant, which is an adhesive substance that can be formed around the valve stem, was applied, and (4) teflon tape was wrapped over the vacuum bag sealant to apply pressure, forcing the air away from the loctite to allow it to cure.

Before the valve and seal were pressure tested, the teflon tape and vacuum bag sealant were removed. This provided visibility when a leak occurred so that the area of the leak around the stem could be pinpointed.

The first seal was attempted at zero pressure with wet surfaces and the cure time was 22 hours 15 minutes. At 50 psig, a slow leak was immediately evident at the back of the stem. In this and all subsequent tests, the valve was left in the full open position to permit flow through it. A second attempt to seal the leak, allowing a cure time of 23 hours 25 minutes, yielded identical results. Even when the cure time was increased to 100 hours, the valve leaked immediately upon pressurizing the line.

The difficulty in sealing the valve could be attributed to either of two possibilities. The vacuum sealant and teflon tape may not have been successful in eliminating the air from the vicinity of the loctite, thus preventing cure. The second possibility is that the gap which the sealant had to fill, estimated at 0.015 inches, was too large for the type of sealant used.

With this second possibility in mind, a different type of loctite sealant, Grade AVV with a much higher viscosity and a maximum gap fill of 0.015 inches, was obtained. The valve was sealed using the same procedure except with grade AVV sealant substituted for grade AA. After a cure time of 1 hour 30 minutes, the valve withstood 50 psig for five minutes, but a very slow leak began 3-1/2 minutes after the pressure was increased to 100 psig.

It is felt that the size of the leak induced in the valve was the major factor contributing to the continuing failure to effect a seal. This points up, however, a possible limitation on the techniques used. A summary of the tests performed with wet surfaces at zero pressure on the valve is given in Table V-4.

Table V-4 Zero Pressure Systems Test, Valve Repair

CONDITIONS	RESULTS
Wet surfaces, zero pressure, Grade AA sealant - Cure Time = 22 hr. 15 min.	Immediate leak @ 50 psig
Repeat, except Cure = 23 hrs. 25 min.	Immediate leak @ 50 psig
Repeat, except Cure = 100 hrs.	Immediate leak @ 50 psig
Repeat procedure using Grade AVV sealant - Cure Time = 1 hr. 30 min.	No leak after 5 min. @ 50 psig. Very slow leak after 3.5 min. @ 100 psig.

2. High Temperature Test

In order to determine the relationship between cure times and temperature, a series of tests was conducted in which the test section was raised to a temperature above 130°F before a repair was initiated. Testing was performed with hot ($T > 130°F$) water in the line at zero system pressure.

Test Specimen No. 2 was sealed according to the normal procedure, with wetted surfaces, and at a temperature of approximately 135°F. Testing was begun immediately after sealing was complete; therefore, actual cure time was on the order of two to four minutes. The temperature of the water in the line was originally 145°F. This fitting was tested at five minute intervals at 50, 100, and 150 psig, and for 18 hours with tap water at 150 psig. No leaks were evident at any time during these tests.

Test Specimen No. 3, configured similarly to test specimen No. 1 with a notch filed in a straight section of tubing, was sealed with the wetted tube surface at 140°F. As was the case with test specimen No. 1, a preliminary wrap of self-vulcanizing tape was applied before the nominal sealing procedure was initiated. Testing was begun immediately after sealing with the water temperature originally at 145°F. No leaks were evident after five minute dwells at 50 and 100 psig, but a leak did begin after 15 seconds at 150 psig. It is theorized that the original layer of self-vulcanizing tape acted as insulating material, thus keeping the loctite sealant closer to room temperature (76°F). The sealant would then require a cure time greater than the two to four minutes provided; therefore, the incomplete cure eventually produced a leak. An identical test performed on test specimen No. 1 produced very similar results, except that the leak was evident at 100 psig. A summary of the tests performed with hot water is given in Table V-5.

Table V-5 High Temperature Tests

CONDITIONS	RESULTS
<u>Specimen No. 2</u> - Normal sealing procedure - wet surface temp. = 135°F, Water temp. = 145°F, 5 min. ea. @ 50, 100, 150 psig, Cure Time < 5 min.	No leak
18 hrs. - tap water @ 150 psig	No leak
N_2 @ 150 psig	No leak
<u>Specimen No. 3</u> - Preliminary wrap of self-vulcanizing tape, then normal sealing procedure; wet surface temp. = 140°F, water temp. = 145°F; Cure Time < 5 min.	
5 min. @ 50 psig	No leak
5 min. @ 100 psig	No leak - leak evident after 15 sec. @ 150 psig
<u>Specimen No. 1</u> - Sealing procedure identical to Specimen No. 3; Wet Surface & Water Temp. = 135°F; Cure Time < 5 min.	
5 min. @ 50 psig	No leak at 50 psig - leak started immediately upon application of 100 psig.

3. Low Temperature Test

An analogous group of tests was performed, at zero system pressure, in which the test specimen was placed in an ice bath to lower its temperature to 32°F. After the sealing procedure was completed the test component was replaced in the bath to ensure that curing took place near 32°F. Pressure testing was accomplished with tap water with the specimen in ambient air.

Test specimen No. 1, the seven-inch straight section, was sealed according to the normal procedure with a cure time of 27 minutes. No leaks were evident after five-minute dwells at 50, 100 and 150 psig. With the pressure maintained at 150 psig, the tape layers were partially cut away and a massive leak was evident before the cut in the tape progressed to the notch in the tube. The test was repeated except that the cure time was limited to 15 minutes. The five-minute dwells at 50 and 100 psig were successfully completed, but a slow leak was visible after 40 seconds at 150 psig. This established that a cure time on the order of 25 minutes is required for an effective seal at 32°F.

The normal sealing procedure was also followed on test specimen No. 2 and a cure time of 30 minutes was allowed. This test section successfully completed the five-minute tests at 50, 100 and 150 psig without leaking and the long-duration test was then conducted. Static water pressure was originally 150 psig, but after 18 hours, the pressure was 123 psig and a minute leak was visible at one end of the tape wrap.

The valve was also tested after a cure of over 19 hours at a temperature of 32°F. The sealant used was grade AVV. An immediate leak was evident as soon as pressure was increased to 50 psig, and it appeared that no seal of any nature was accomplished. When the valve was examined and the stem removed, the loctite along the threads was in liquid form, indicating that cure had not taken place. It is not certain whether an inadequate tape wrap or the cold temperature prevented cure.

A summary of the cold water tests performed is given in Table V-6.

Table V-6 Cold Temperature Tests

CONDITIONS	RESULTS
Specimen No. 1 - Cure Time = 27 Min.	
5 Min. @ 50 psig	No leak
5 Min. @ 100 psig	No leak
5 Min. @ 150 psig	No leak
Tape Cut Away	Leak verified @ 150 psig
Repeat above, except Cure = 15 Min.	
5 Min. @ 50 psig	No leak
5 Min. @ 100 psig	No leak
	Leak after 40 sec. @ 150 psig
Specimen No. 2 - Cure Time = 30 Min.	
5 Min. @ 50 psig	No leak
5 Min. @ 100 psig	No leak
5 Min. @ 150 psig	No leak
18 hrs. @ 150 psig - Water	P = 123 psig after 18 hrs., very small leak visible (≈8-10 drops/hr.)
Valve - Grade AVV sealant - Cure Time = 19 hrs. 18 min.	
50 psig	Immediate large leak Loctite remained liquid- no cure

4. Distilled Water Tests

A fourth series of tests was conducted with distilled water at room temperature with zero line pressure during sealing. This series of tests was conducted because distilled water is known to be an extremely effective solvent for many types of adhesives. It should be noted, since several test specimens were used in many or all of the test series, that each test section was thoroughly cleaned before a new series of tests was begun and the presence of a leak was verified in each case.

Test specimen No. 2 was sealed according to normal procedure with a cure time of 15 minutes at room temperature (75°F). The three-stage leak check was successfully completed.

A ten-minute cure time was allowed for test specimen No. 3 preceeding the five-minute tests at 50, 100 and 150 psig, which were completed with no evidence of a leak. A five-minute test with nitrogen gas at 150 psig was also conducted and no leaks were visible when the test section was immersed in a water bath for the test.

A seal was also attempted on the valve, using distilled water, but an immediate, general leak was obvious when pressure was increased to 50 psig. Cure time was four hours.

Test specimen No. 1 was sealed in the usual manner and allowed a cure time of seven minutes. No leaks were visible after five minutes at 50 and 100 psig, but a massive leak occurred immediately when pressure was increased to 150 psig. The tape was removed and a new seal applied at zero pressure and a cure time of ten minutes was allowed. Tests at 50, 100 and 150 psig with distilled water, and at 150 psig with nitrogen gas with five minute dwells at each pressure, were completed with no leaks visible. The long-duration test, 18 hours with initial line pressure at 150 psig, revealed a slight leak. The pressure at the end of the test was 127 psig. This series of tests indicates the importance of allowing adequate cure time; a three-minute increase in cure time significantly enhanced the sealing capability of the Loctite and tape wraps.

A summary of the tests performed with distilled water is given in Table V-7.

Table V-7 Distilled Water Tests

CONDITIONS	RESULTS
Specimen No. 2 - Cure Time = 15 min.	
5 Min. @ 50 psig	No leaks
5 Min. @ 100 psig	No leaks
5 Min. @ 150 psig	No leaks
Specimen No. 3 - Cure Time = 10 min.	
5 Min. @ 50 psig	No leaks
5 Min. @ 100 psig	No leaks
5 Min. @ 150 psig	No leaks
N_2 @ 150 psig - 5 min.	No leaks
Valve - Cure Time = 4 hrs.	
50 psig	Immediate Leak
Specimen No. 1 - Cure Time = 7 min.	
5 Min. @ 50 psig	No leak
5 Min. @ 100 psig	No leak
150 psig	Immediate, Massive leak
Specimen No. 1 - Reseal, Cure Time = 10 min.	
5 Min. @ 50 psig	No leaks
5 Min. @ 100 psig	No leaks
5 Min. @ 150 psig	No leaks
N_2 @ 150 psig - 5 min.	No leaks
18 hrs. @ 150 psig - distilled water	P = 127 psig after 18 hrs. 5 min., slight leak visible

5. System Pressure Tests

The most difficult condition under which a seal can be attempted occurs when the system is pressurized. In this case the fitting or valve is leaking at the time the primer, loctite and tape wraps are applied. In essence, no cure time at all is provided. Several tests were conducted to establish if an effective seal could be accomplished under such conditions.

Because it was desired that the leaks on which a seal would be attempted be manageable ones, that is, dripping leaks and not spurting streams under pressure, test specimens No. 1 and 3 and the valve were not used in these tests. The leaks induced in those fittings were very large and, when pressurized, emitted a continuous stream of water. The leaks in test specimen No. 2 and a newly prepared specimen No. 4 were small enough to allow sealing to be attempted under pressure. Test specimen No. 4 was composed of two short sections of tubing connected by a union fitting. The flared end of one of the sections of tubing was notched on the side to be placed against the union, thus producing an adequate leak (see Table V-2).

Over a dozen tests were performed at pressures ranging from 50 to 150 psig. Various techniques were used in an attempt to define the limiting criteria for leak sealing under pressure. It became obvious very quickly that unless the leak rate was very slow, a seal could not be obtained. The dripping water tended to carry away the liquid sealant before the self-vulcanizing and teflon tape wraps could be applied. Even when the self-vulcanizing tape was quickly wrapped around the fitting the continually dripping water evidently forced the sealant away from the fitting, spreading it out along the interior of the tape. The continually wet surface might also have prevented the primer from drying properly.

In one of the initial tests, specimen No. 2 was sealed according to the normal procedure with a static line pressure of 150 psig. The original leak was very slow (5-10 drops/hour). After the sealing procedure was complete, the pressure was maintained at 150 psig for five minutes with no leaks evident. Because of the slow original leak rate, however, the seal was not conclusive. The tape was then removed and the test specimen thoroughly cleaned and placed back in the line to be resealed. The new leak rate at 150 psig was much higher than the previous rate, on the order of 10 drops/min. The leak continued during sealing and after sealing was complete, at near the original rate. These tests indicate the importance of leak rate as a limiting criteria.

Test specimen No. 4 was sealed at a pressure of 125 psig, and when the tape wrapping was complete, the pressure was increased to 150 psig. The original leak rate was approximately 1 drop/minute. After 17 minutes at 150 psig, the leak was visible at the surface of the tape. When the tape was removed and the fitting taken apart, it was seen that much of the sealant had remained in liquid form; this indicated that a complete cure had not taken place.

The above test was repeated two more times and the results were similar. In one case the leak propagated to the surface of the tape wrap one minute after the sealing procedure was complete; in the other instance the leak surfaced after 11 minutes.

Since there was an average delay of almost ten minutes between the time the sealing procedure was completed and the time the leak was again visible at the tape surface, it was theorized that a double wrapping procedure might provide an effective seal. After the first layer of teflon tape was applied, its surface was sprayed with primer, loctite sealant was applied, and a second wrap of self-vulcanizing and teflon tape was placed over the first. It was hoped that the loctite between tape layers would have sufficient time to cure before the leak propagated past the first wrap of teflon tape. Of course, it was questionable whether even cured loctite could provide an effective seal between two layers of tape on such an irregular surface.

Several tests were performed to evaluate this proposed procedure. A line pressure of 125 psig was applied to test specimen No. 4 during sealing. It was noted that the second layer of self-vulcanizing tape did not adhere well to the loctite-wetted teflon tape. Some degree of difficulty was experienced in trying to pull the self-vulcanizing tape tight around the first tape wrap since it continually slipped on the teflon tape. The second sealing process was accomplished, however, and the pressure was increased to 150 psig. Thirteen minutes later the leak had made its way to the surface of the second tape layer. With the pressure maintained at 150 psig, a third sealing process was applied over the first two. Twenty-six minutes after this third layer was complete, the leak was again evident at the surface. This series of tests indicated that multiple tape layers were not sufficient to provide an effective seal, at least not at the line pressures which were maintained.

To establish the effect of line pressure on the overall sealing technique, a group of tests was performed at lower pressures during sealing. Specimen No. 4, thoroughly cleaned and with a slow initial leak rate, was subjected to 50 psig during a double sealing procedure. This pressure was maintained for one hour after the second wrap of teflon tape was applied, and at the end of that hour no evidence of the leak was visible. The long-duration pressure test was begun immediately with an initial pressure of 50 psig. After almost 19 hours, the line pressure was 48 psig and the seal remained intact. All the tape was then cut away from the fitting and the line was repressurized to 50 psig for five minutes. In this test and in subsequent tests at 100 and 150 psig for five minutes each, the fitting showed no evidence of a leak. When the fitting was taken apart immediately after testing, loctite in solid (cured) form was observed along the threads of the union fitting and connecting nut, thus providing the seal.

When a similar series of tests was performed at the same pressures but with a larger initial leak rate, a complete seal was never accomplished. With up to three complete wrapping processes applied, the leak rate was reduced to one-fourth its original value (from 1 drop every 25 seconds to 1 drop every 95 seconds, for example), but was never completely stopped. There was a 15 to 25 minute delay between the time the tape wrapping was complete and the reappearance of the leak. When the tape was removed from the fitting, the leak rate was slower but still very close to the original rate.

These tests seemed to establish several important points. Both leak rate and system pressure are vital factors in determining whether or not an attempted seal will be successful. At low leak rates (1 drop every several minutes) and low system pressures (50 psig), a successful seal is feasible. At higher leak rates and pressures, effective seals were not achieved. The repeatability of the results was not conclusively established, but feasibility was demonstrated. A summary of the tests performed with a pressurized system during sealing is detailed in Table V-8.

6. Valve Repair Tests

A completely effective seal was accomplished on the valve. The tests were conducted with all surfaces dry and the system pressure at zero psig. Normal sealing procedure was followed using the loctite grade AVV sealant and a cure time of four hours and forty minutes was allowed at room temperature. The valve then successfully completed five-minute tests with tap water at 50, 100 and 150 psig. The long-duration test was also a success; after 18 hours the pressure was still at 150 psig and no leaks were visible. Finally, the valve did not reveal any leaks when the system was pressurized with nitrogen gas at 150 psig for five minutes.

Table V-8 System Pressure Tests

CONDITIONS	RESULTS
Specimen No. 2 - Slow initial leak rate, repair @ 150 psig - pressure was maintained for 5 min. after seal was completed.	No leak evident (see later tests)
Specimen No. 2 - Repeat above with larger (X 60) initial leak rate.	Continuous leak
Specimen No. 4 - Very slow initial leak rate - seal @ 125 psig, increase pressure to 150 psig after repair was completed.	Leak evident after 17 min. @ 150 psig
Specimen No. 4 - Repeat above test.	Leak after 1 min @ 150 psig
Specimen No. 4 - Repeat above test.	Leak after 11 min @ 150 psig
Specimen No. 4 - Double tape process (normal sealing procedure performed, then repeated over first layer) 125 psig during taping, 150 psig after repair complete.	Leak evident after 13 min. @ 150 psig
Third tape layer applied over existing leak and tape, maintain 150 psig.	Leak visible 26 min. after third layer complete
Specimen No. 4 - Double taping - maintain 50 psig during and after repair.	No leak visible 1 hr. after repair complete
Long duration test - 50 psig	P = 48 psig after 18 hrs. 39 min - no leak evident
Tape cut away - 5 min @ 50 psig 5 min @ 100 psig 5 min @ 150 psig	No leak No leak No leak
Specimen No. 4 - Leak rate initially at 1 drop/25 sec., 50 psig maintained-first seal process performed.	Leak rate slowed to 1 drop/35 sec.
Second taping applied - 50 psig	Leak evident after 25 min, leak rate = 1 drop/min
Third taping - 50 psig	Leak evident after 20 min, leak rate = 1 drop/95 sec.
Tape cut away - 50 psig	Leak rate @ 1 drop/40 sec.
Specimen No. 4 - Two wraps applied @ 50 psig.	Leak visible after 15 min. leak rate @ 1 drop/2.25 min.
Tape cut away	Leak rate @ 1 drop/55 sec.

This total success after seven separate failures aptly points out the degree of difficulty involved in sealing this particular valve leak. All of the factors which could be controlled had to be favorable before a seal was obtained. The valve was dry, unpressurized and at room temperature, and a long cure time of over four hours was provided. The factor which could not be controlled, the massive induced leak, was the major factor working against a successful repair. A smaller leak, it is thought, would have lent itself to repair much more readily. Nevertheless, it was proven that the techniques employed were sufficient in at least one case to accomplish a seal under the conditions specified. Feasibility, not repeatability, was demonstrated.

7. Tank Repair Tests

At the conclusion of the leak repair program, a series of tests was performed to determine if small leaks in water tanks, that is, leaks in surfaces with relatively large radii of curvature, could be effectively sealed using the same techniques and materials that were used on the other test specimens. A water tank was simulated in the test apparatus by attaching a thin (1/8") aluminum sheet to an eight-inch diameter flange, see Table V-2. A leak was produced by machining a small hole (.010" to .015" in diameter) in the center of the aluminum sheet. The tank was filled with water and pressurized when necessary through fittings in the flange.

It was immediately evident that the original induced leak was much too large for meaningful testing. Even when system pressure was zero, the slight (<0.20 psi) hydrostatic head of the water in the tank produced a steady trickle of water through the hole. Nevertheless, two attempts were made to seal the leak with a loctite-tape patch at zero system pressure. Both attempts were unsuccessful.

The aluminum plate was manually peened in the area of the leak in an attempt to reduce the hole size. This was accomplished with the result that at a system pressure of 50 psig, the leak was very slow but still discernible.

Several problems which were not present when sealing leaks in fittings or components became important when the tank seal was tried. It was very difficult to ensure that all air was forced from the vicinity of the leak. The pressure that could be applied by hand was variable. Much of the liquid sealant was squeezed from beneath the patch when the air was forced out. The tendency for the sealant to flow down along the tank wall would not be as great in the zero gravity of a Space Station, but hand pressure would still force liquid out from beneath the patch. A tight tape wrap, as could be applied by winding the tape around a tube or fitting, was virtually impossible to obtain on the flat tank surface. The normal procedure had been to stretch the teflon tape as it was wound around the tube or fitting so that it would tend to tighten down on the fitting. When the teflon tape was stretched before it was applied to the tank, it eventually pulled itself free from the wall. Since its purpose was simply to hold the patch in place, the teflon tape was applied with as little tension as possible in later attempts.

Four attempts were made to seal the tank leak while system pressures of from 50 to 145 psig were maintained. None of the attempts to seal a tank under pressure were successful, nor was there any evidence of a decrease in the leak rate. The sealing procedure was slightly different in each attempt; for instance, grade AA sealant was used in three attempts and grade AVV in the other attempt. The general procedure of applying primer, sealant, and tape was followed, however.

In subsequent attempts, the system pressure was maintained at zero psig while the patch was applied, and a cure time of 20 to 30 minutes was allowed before pressure was applied. A patch of self-vulcanizing tape, vacuum sealant and grade AA sealant was applied to the primed surface and the lower edge of the patch was taped in place with teflon tape under very slight tension. The upper portion of the patch was peeled back and several more drops of sealant were applied around the leak before the patch was finally covered with teflon tape. A cure time of 22 minutes was allowed; and 20 minutes each at pressures of 50, 100 and 150 psig revealed no detectable leak. A system pressure of 150 psig was applied for a total of 19 hours, and at the end of that time, system pressure was still at 150 psig although some water was visible at one side of the patch. When the patch was removed, the tank surface was wet and the leak still appeared to be present since water droplets were evident at the original leak position during 15 minutes of observation. The test was continued for three hours and 40 minutes at a pressure of 150 psig with no further evidence of a leak, nor did nitrogen gas at 150 psig produce any detectable leak.

Several questions arise as a result of the water being present under the patch when it was removed, and because several droplets of water were observed emerging from the leak position immediately afterward. It is possible that the sealing process was complete only after some water had leaked from the tank and that this water did not evaporate quickly because of the presence of the patch. The water droplets seen at the original leak position could have been trapped in the wall during the sealing process and then emerged only when the patch was removed. It is significant that only two or three droplets were observed emerging and no additional water was visible in the remainder of the 3 hour 40 minute test.

Another series of tests was conducted on a second "tank leak" and, although there seemed to be a significant decrease in leak rate, a complete seal was not attained. It is concluded, after eleven separate tests on two different tanks, that the materials and techniques used are very close to being sufficient to obtain seals in tank leaks. Nevertheless, as in the case of fittings under pressure, the number of successful seals attained was not sufficient to justify a high degree of confidence in obtaining a seal in any one specific case. It does not seem feasible that successful seals can be accomplished in tanks which are pressurized during application of the patch. This conclusion is based on the difficulties observed in sealing at zero pressure and on the basis of the four unsuccessful attempts made at various pressures.

E. LEAK REPAIR TEST CONCLUSIONS

The following conclusions can be drawn from the tests conducted on leak repairs using the techniques and materials chosen:

1) The procedures to be followed are very simple and can be accomplished by an inexperienced person.

2) Effective seals can be obtained on tubing and fittings when repaired at zero system pressure. Successful tests were conducted with both tap and distilled water in the line, at temperatures ranging from 33°F to 145°F. These seals can withstand pressures up to 150 psig for at least 18 hours.

3) Cure time of the loctite sealant is a function of temperature as follows:

25 min @ 33°F	Note: surface primed with
15 min @ 75°F	MIL-S-22473C1 primer,
5 min @ 135°F	Grade "T".

4) Sealing under pressure is feasible only under very favorable conditions; low leak rates and/or low system pressures (low leak rates are defined as being barely discernible under casual observation; low pressure is equal to or less than 100 psig). Repeatability of sealing under pressure was not established.

5) The large leak (.015" gap) in the valve was very difficult to seal. One attempt in seven was successful.

6) Tank repairs under pressure were not achieved.

7) Tank seals at zero pressure may be possible in some cases where the original leak rate is very slow and the system pressures which subsequently may exist are relatively low (<100 psig).

8) Additional testing on fittings under pressure and on tank leaks may reveal adequate techniques using the same materials which can provide successful seals.

VI. INFLIGHT MAINTENANCE SIMULATION TEST PANEL

A simulation test panel was constructed, as part of the contract requirements, to be used for the purposes of testing various elements of the tool kit, the OWS stowage locker mock-up, the leak repair kit, and the fluid removal tool. The tests will be performed by NASA, after the conclusion of this contract, in a KC-135 aircraft to simulate a zero-g environment. The major tasks to be performed during these tests are:

1) Fluid removal in zero gravity;
2) Fluid component removal;
3) Fluid component replacement;
4) Fluid fill and bleed;
5) Leak repair of tubes and fittings;
6) Evaluation of tool usage on the fastener task panel;
7) Evaluation of surface tension effects in zero-g;
8) Human performance in zero-g while performing maintenance tasks;
9) An evaluation of the design, human factor aspects, and application of the tool kit, tool kit contents, the fluid removal pump, and the leak seal repair kit.

A schematic of the test panel is shown in Figure VI-1, and a photograph of the panel is shown in Figure VI-2. The fluid system will contain tap water and will be pressurized to 75 psig. The pressurized system will be used to leak check the system after a leak repair or component replacement, and to supply water to the remainder of the fluid system. The fastener task panel contains several fasteners designed to test human performance in zero-g, to evaluate tool operation, and for an evaluation of common fastener design in a zero-g environment.

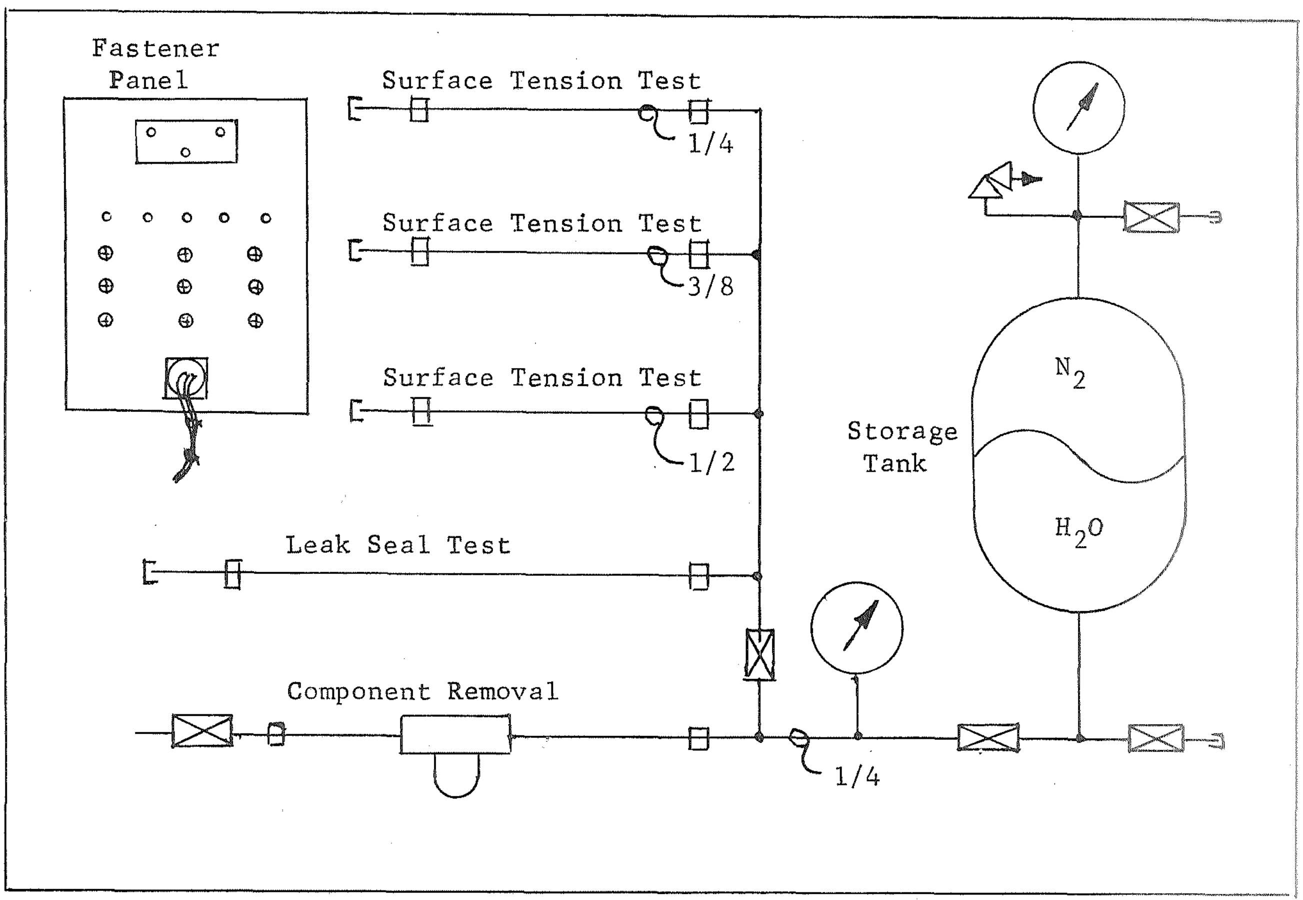


Figure VI-1 Simulation Test Panel Schematic

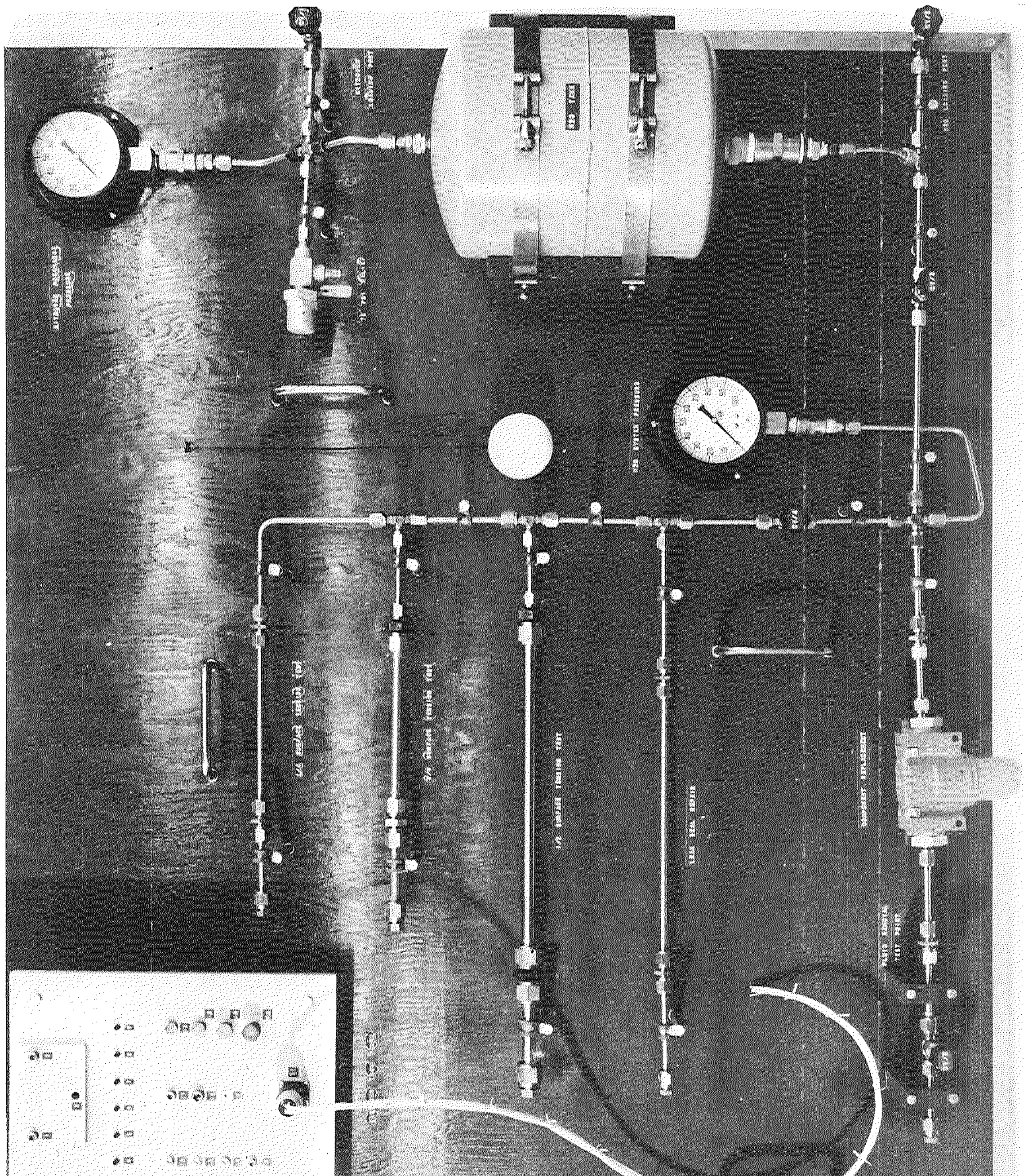


Figure VI-2 Inflight Maintenance Simulation Test Panel

The water storage tank is a two-gallon bladder-type tank that has a one-gallon water capacity. When initially pressurized, the tank pressure is 75 psig, which depletes to 35 psig when the one gallon of water is expended. A volume-pressure calibration curve delivered with the test panel can be used to monitor the water volume remaining in the tank. The nitrogen pressure gage is used as the indicator. The tank may be pressurized with either nitrogen or air through the pressurization loading port. The system has a relief valve set at 80 psig to prevent system over-pressure.

The fluid system maintenance test section consists of 1/4-inch tube, various fittings, and a fluid component. This test section is used to test the fluid removal tool, and to evaluate human performance and tools during the removal and replacement of a fluid component at zero-g conditions. Certain elements of the fluid removal tool cannot be tested in a one gravity environment, and requires zero-g for the evaluation. These items are fluid behavior in zero-g, the efficiency of the phase separator screen, and fluid recharge and bleed of the system.

The leak repair section is fabricated from 1/4-inch stainless steel tubing and has extra spool pieces with built-in leaks. The leaks are induced at the fitting flares, fluid fittings, and in the middle of the tube length. During the zero-g tests, the test subject will install the test spool, open the shut-off valve which will initiate the leak, and then proceed to repair the leak with the leak seal repair kit. Several mechanical manipulations will also be tested during the operation.

The surface tension tests will be used to evaluate the surface tension effects of a fluid (water) within the boundary conditions of a tube at zero-g conditions. Of particular interest will be an evaluation of the accelerations incurred during the removal and replacement of a fluid filled tube in zero-g. The objective of the test is to determine if surface tension forces are sufficient to contain a fluid within a tube system while a component or tube section is being removed from the system. A successful test here would indicate that non-toxic fluid may not have to be removed from a system prior to maintenance operations. This could pave the way for a very simple method of fluid containment that utilizes the effects of a zero-gravity environment.

The surface tension test consists of three tubes; 1/4, 3/8, and 1/2 inch in diameter. The 1/2-inch tube is exactly twelve inches long and is a test of the maximum head pressure that theoretically can be contained at low-gravity in a 1/2-inch tube. Each tube will be removed and held in both the lateral and transverse attitudes, and then will be accelerated until the fluid drops out of the tube. Normal accelerations incurred during removal and replacement will also be evaluated.

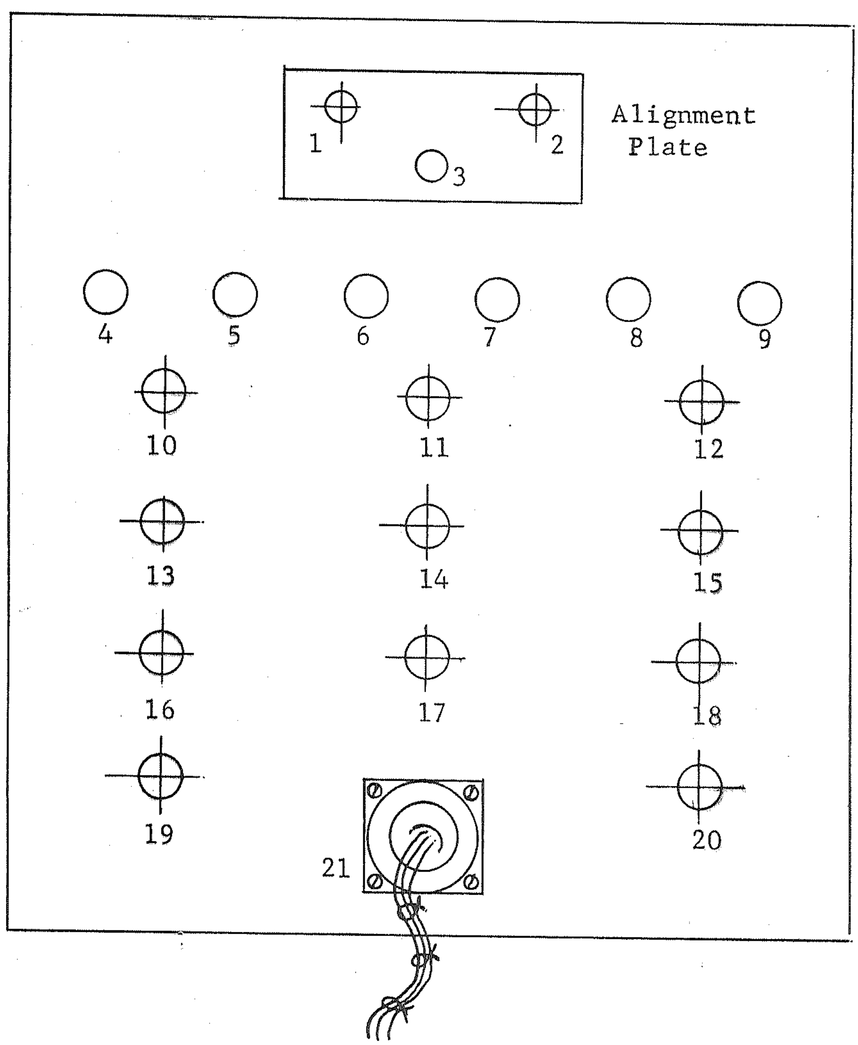
The fastener task panel will be used to test human performance, permissible torque levels, tool application, restraints, and the design and application of common fasteners in a zero-g environment.

The task panel contains screws and bolts that range in size from a 10-32 screw to a 7/16-inch bolt. The fastener heads include hexagon heads, allen socket head cap screws, fillister screw driver heads, phillips head screws, and hi-torque no. 1 screws. The size, location, and tool that will be used on each fastener is shown in Table VI-1. Each fastener will be torqued to a preset value prior to the KC-135 test to evaluate both astronaut body restraints and the effects of human performance at different torque levels. After removal and re-installation, a torque wrench will be used to evaluate the application of torque.

A hammer is used to drive in roll pins; and the brass punch is used to align a plate prior to attaching the plate to the task panel. The electrical connector will be removed by hand first, and then with the electrical connector pliers. Dexterity and alignment skills will be evaluated when reconnecting the connector. The electrical leads will be stripped and connected, using the electrical wire and connectors contained in the tool kit.

Table VI-1 Fastener Task Panel

Fastener Identification	Description	Tool Used
1, 2, 11	1/4-28 Allen Socket Head	3/16 Allen Socket
3	.281 Dia. Alignment Hole	Brass Punch
4,5,6,7,8,9	3/16 Roll Pin	Hammer and Punch
10	10-32 Fillister Head Screw	1/4 Screwdriver
12	1/4-28 Hex Head	7/16 Std. Socket
13	10-32 Phillips Head Screw	Phillips Screwdriver
14	5/16-24 Allen Socket Head	1/4 Allen Socket
15	5/16-24 Hex Head	1/2 Flare Nut Wrench
16	10-32 Hi-Torque #1	Hi-Torque #1 Socket
17	10-32 CSK Allen Socket Head	1/8 Allen Socket
18	3/8-24 Hex Head	9/16 Deep Socket
19	10-32 Allen Socket Head	5/32 Allen Socket
20	7/16-20 Hex Head	5/8 Std. Socket
21	Electrical Connector	Connector Pliers



In addition to the evaluation of manual skills, an evaluation will be made on the amount of training required to use the tool kit, fluid removal tool, etc. A minimum amount of training and equipment orientation will precede the tests and the test subject will be evaluated on his retention capability.

Besides the technical and procedural aspects of this test, the primary objectives are to evaluate the design and human factor considerations of the tool kit, sponge rubber tool retention system, detent actuation, tool nomenclature, tool carrier, spares translation container, etc.

The data obtained from these tests will be directly applicable to the Skylab Tool Kit and scheduled maintenance tasks, and will serve to broaden the base of data required for future long-duration manned missions.

APPENDIX A

DEVELOPMENT PHASE DESIGN DRAWINGS

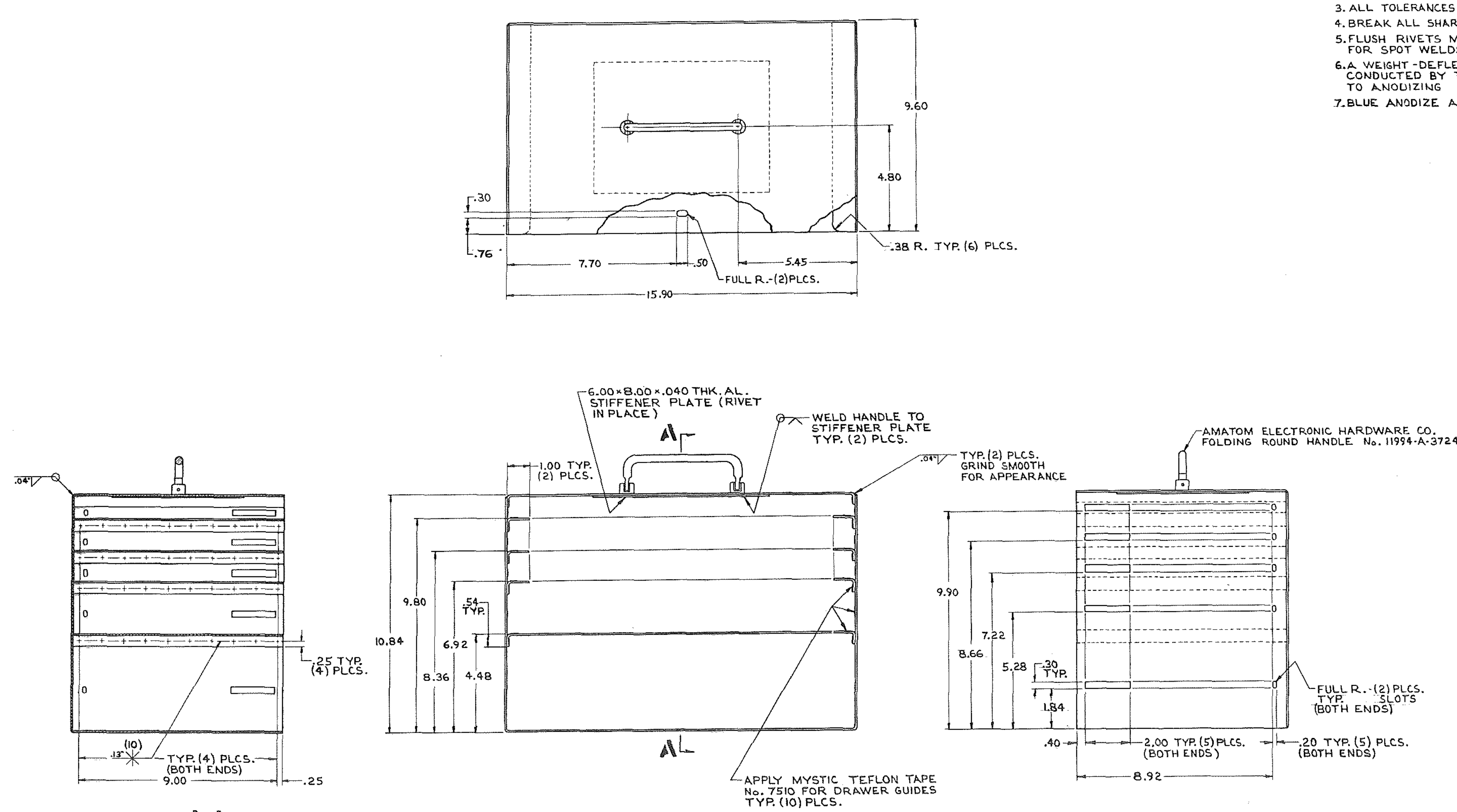
APPENDIX A

DESIGN DRAWINGS

Martin Marietta Corp. Drawing Number	Page	Title
RES-31650	3	Astronaut Tool Kit, Main Cabinet
RES-31651	4	Drawer Details
RES-31652	5	Drawer Engraving
RES-31653	6	Drawer No. 1 Tool Layout
RES-31654	7	Drawer No. 2 Tool Layout
RES-31655	8	Drawer No. 3 Tool Layout
RES-31656	9	Drawer No. 4 Layout
RES-31657	10	Drawer No. 5 Layout
RES-31658	11	Drawer Detent
RES-31660	14	Stowage Locker Mock-Up
RES-31661	15	Locker Retention Device
RES-31670	16	Fluid Removal Tool, Assembly
RES-31671	17	Pump Assembly
RES-31672	20	Coupling Assembly
RES-31673	22	Seal, Mold
RES-31680	23	Astronaut Tool Carrier, Assembly
RES-31681	24	Case Assembly
RES-31682	25	Brush Assembly
RES-31683	26	Details
RES-31690	27	Test Panel Layout
RES-31691	28	Fastener Panel

SYM	ZONE	DESCRIPTION	DATE	APPROVED
A	-	DIMENSIONS FINALIZED FOR RELEASE TO SHOPS	11/25	
B	-	INCORPORATED DETENT SLOTS & STIFFENER PLATE	3/15	

NOTES:
1. MATERIAL TO BE .040 THK. 6061-T6 ALUMINUM
2. ALL BEND RADII TO BE .09
3. ALL TOLERANCES TO BE ±.02
4. BREAK ALL SHARP EDGES
5. FLUSH RIVETS MAY BE SUBSTITUTED FOR SPOT WELDS
6. A WEIGHT-DEFLECTION TEST SHALL BE CONDUCTED BY THE CONTRACTOR PRIOR TO ANODIZING
7. BLUE ANODIZE ASSEMBLY



SECTION A-A

MARTIN MARIETTA CORPORATION

M. HUSSEY / 1646 / 11-5-?

ASTRONAUT TOOL KIT
MAIN CABINET

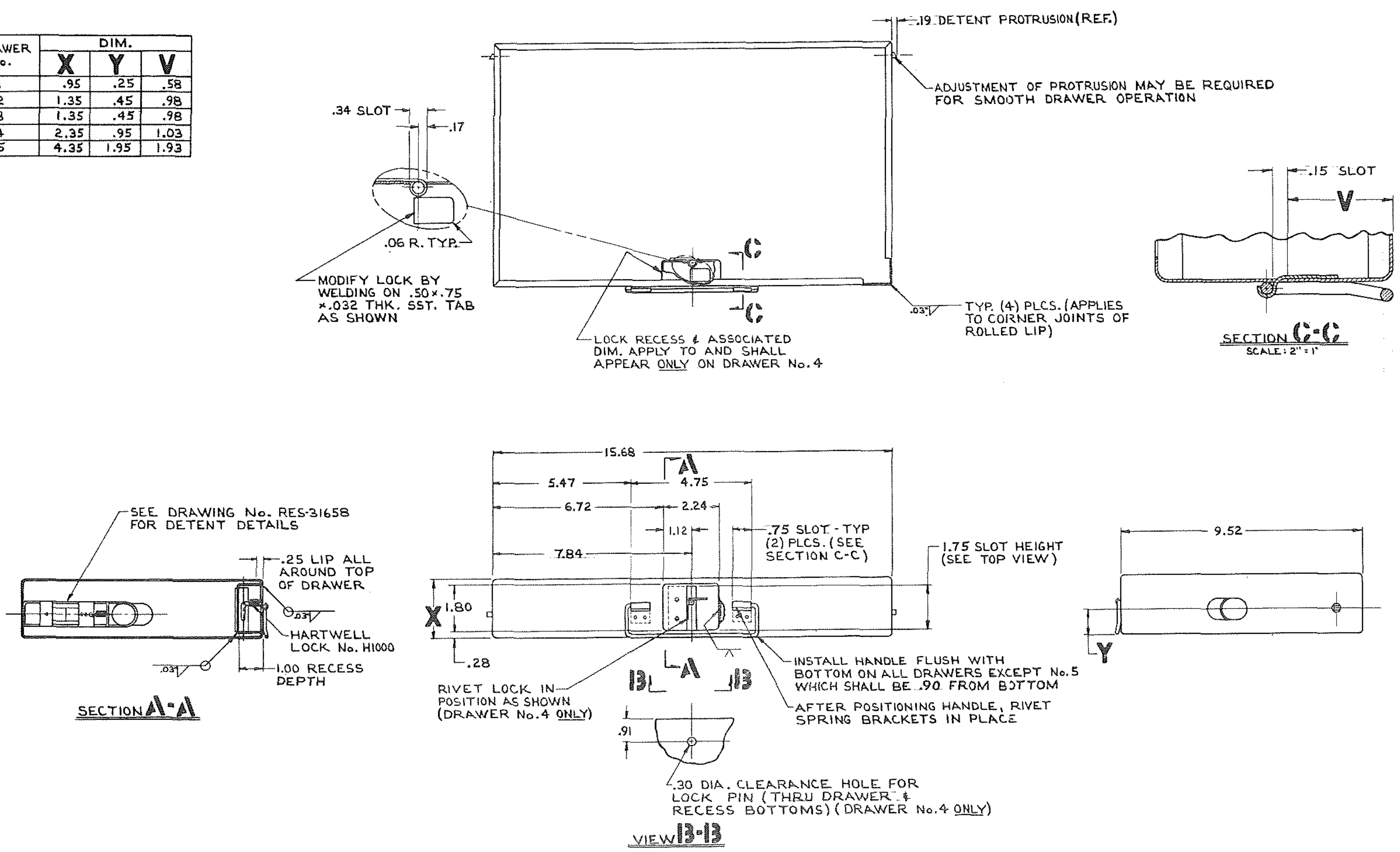
SIZE	CODE IDENT NO	
E	04236	RES-31650

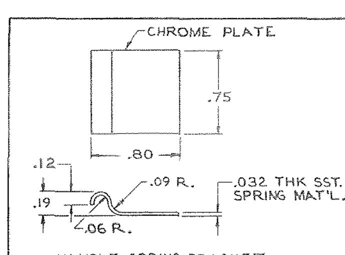
SCALE 1/2" = 1"

SYM	ZONE	DESCRIPTION	DATE	APPROVED
A	-	LOCK MOUNTING & DIMENSIONS FINALIZED FOR RELEASE TO SHOPS	11/25	
B	-	INCORPORATED MODIFICATION TO DETENTS & HARTWELL LOCK TABS	3/15	

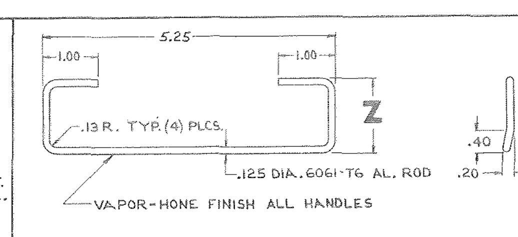
NOTES:
1. MATERIAL TO BE .032 THK. 6061-T6 ALUMINUM
2. ALL BEND RADII TO BE .09
3. ALL TOLERANCES TO BE ±.02
4. BREAK ALL SHARP EDGES
5. NON-ALUMINUM PARTS TO BE ASSEMBLED AFTER ANODIZING
6. BLUE ANODIZE ASSEMBLY WITH EXCEPTION OF HANDLES

DRAWER No.	DIM. X	DIM. Y	DIM. V
1	.95	.25	.58
2	1.35	.45	.98
3	1.35	.45	.98
4	2.35	.95	1.03
5	4.35	1.95	1.93





HANDLE SPRING BRACKET SCALE: 2"=1"



HANDLE SCALE: FULL

DRAWER No.	DIM. Z
1	.85
2	1.25
3	1.25
4	1.30
5	1.30

LIST OF MATERIAL

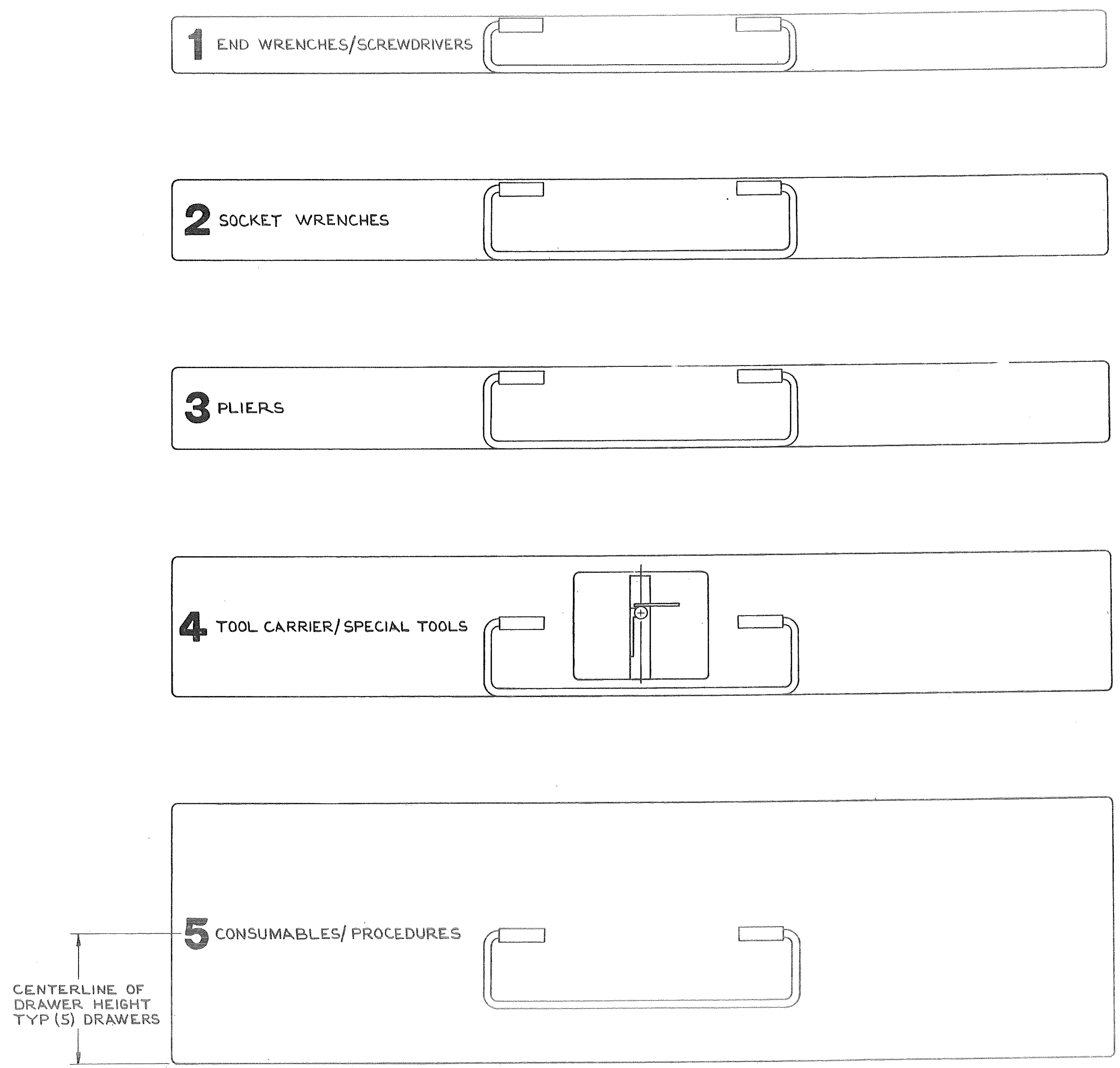
M.HUSSEY/1640/11-16-70

MARTIN MARIETTA CORPORATION

ASTRONAUT TOOL KIT DRAWER DETAIL

E 04236 RES-31651

SCALE 1/2"=1"



NOTES:

1. NUMBERS TO BE 1/2" HIGH & LETTERS TO BE 3/16" HIGH - 6 PER INCH (CENTERED AS SHOWN)
2. NUMBERS & LETTERS TO BE FILLED WITH FLAT WHITE PAINT

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED

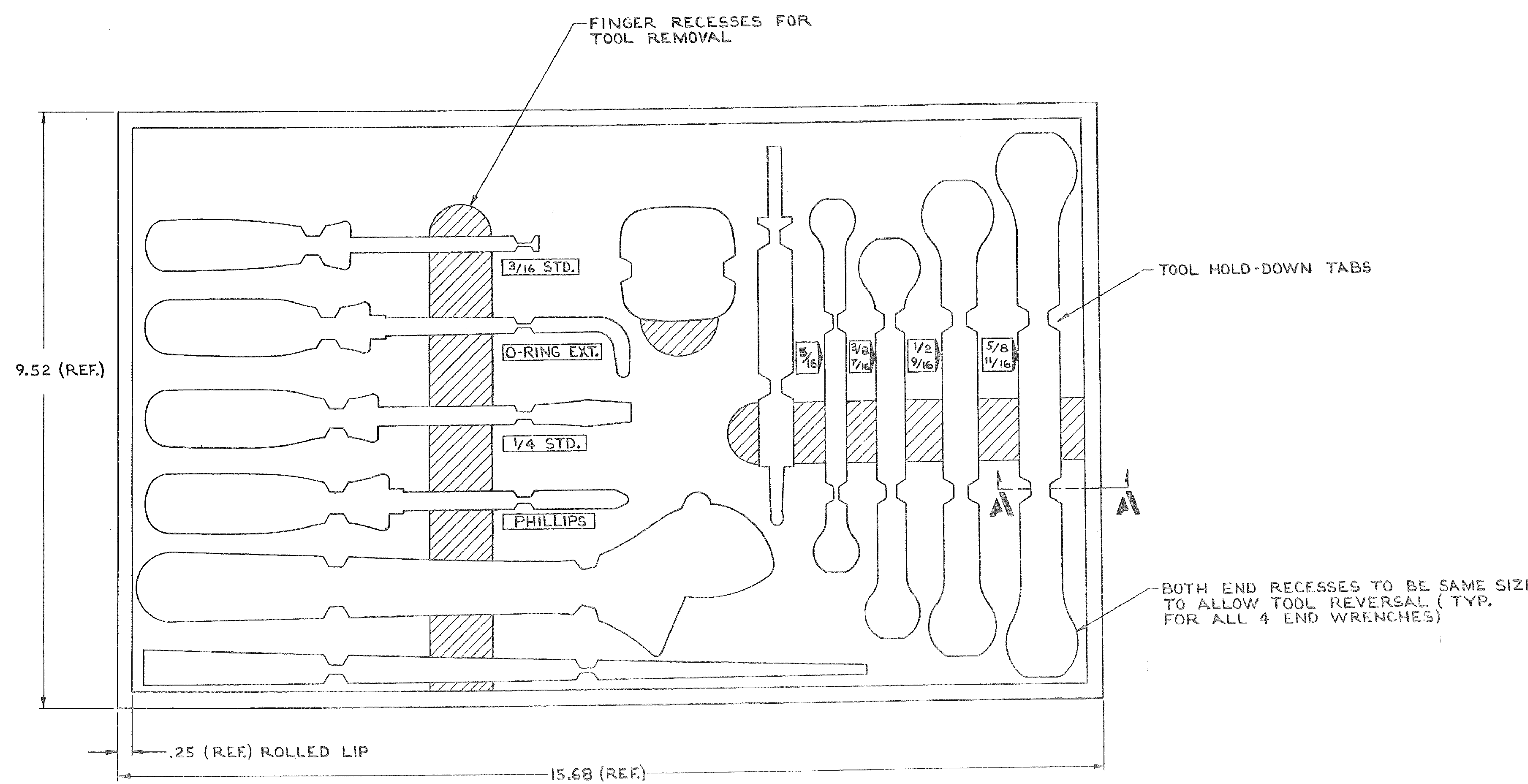
ASTRONAUT TOOL KIT
ENGRAVING DETAIL
12/1/70

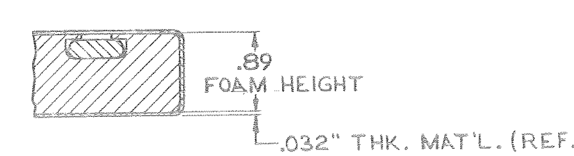
SIZE	CODE IDENT NO.	
D	04236	RES-31652
SCALE FULL	M. HUSSEY	SHEET

DEN 041607-01 (10-68)

SYM	ZONE	REVISIONS DESCRIPTION	DATE	APPROVED

NOTES:
1. MAT'L. TO BE ARMAFLEX SPONGE RUBBER





SECTION A-A

ASTRONAUT TOOL KIT
DRAWER No. 1 LAYOUT

SIZE	CODE IDENT NO.	
D	04236	RES-31653
SCALE FULL	M. HUSSEY	SHEET

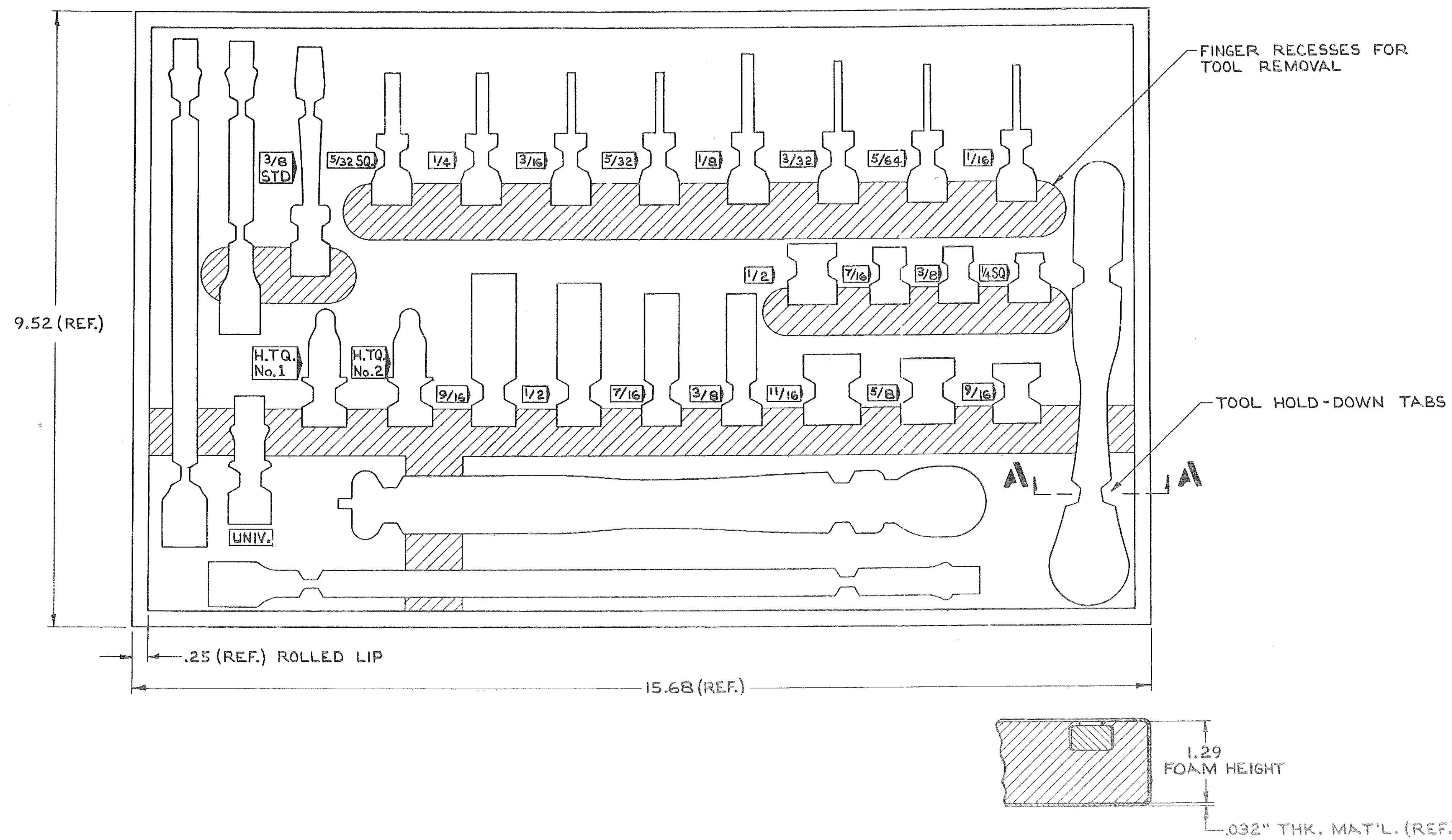
DEN 061607-01 110-681

REVISIONS

SYM	ZONE	DESCRIPTION	DATE	APPROVED

NOTES:

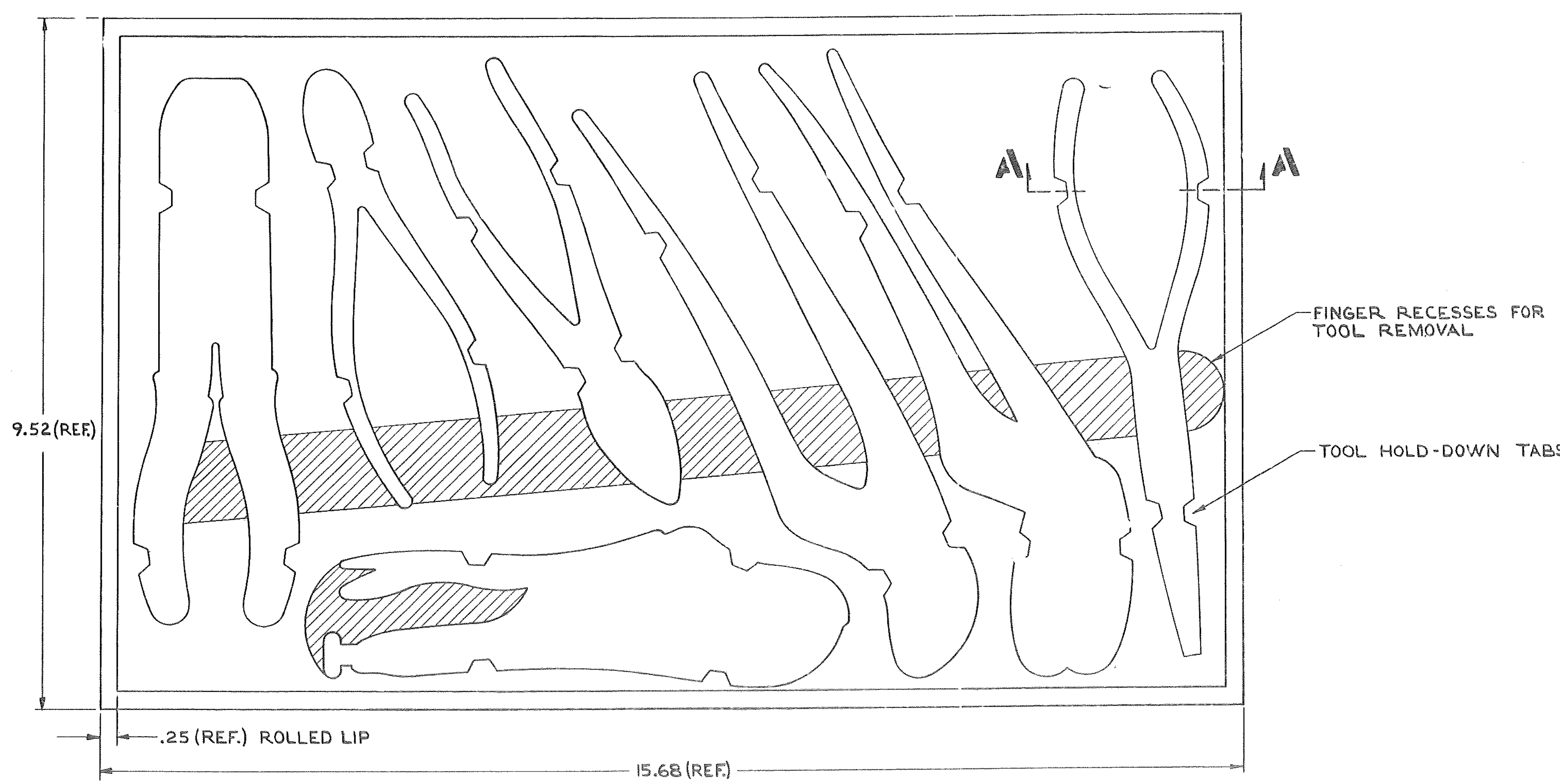
1. MAT'L. TO BE ARMAFLEX SPONGE RUBBER

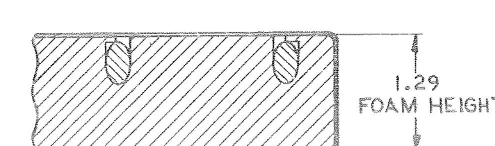


ASTRONAUT TOOL KIT
DRAWER No. 2 LAYOUT

SIZE	CODE IDENT NO.	
D	04236	RES-31654
SCALE FULL	M. HUSSEY	SHEET

NOTES:
1. MAT'L. TO BE ARMAFLEX SPONGE RUBBER





SECTION A-A

REVISIONS		
SYM	ZONE	DESCRIPTION	DATE	APPROVED

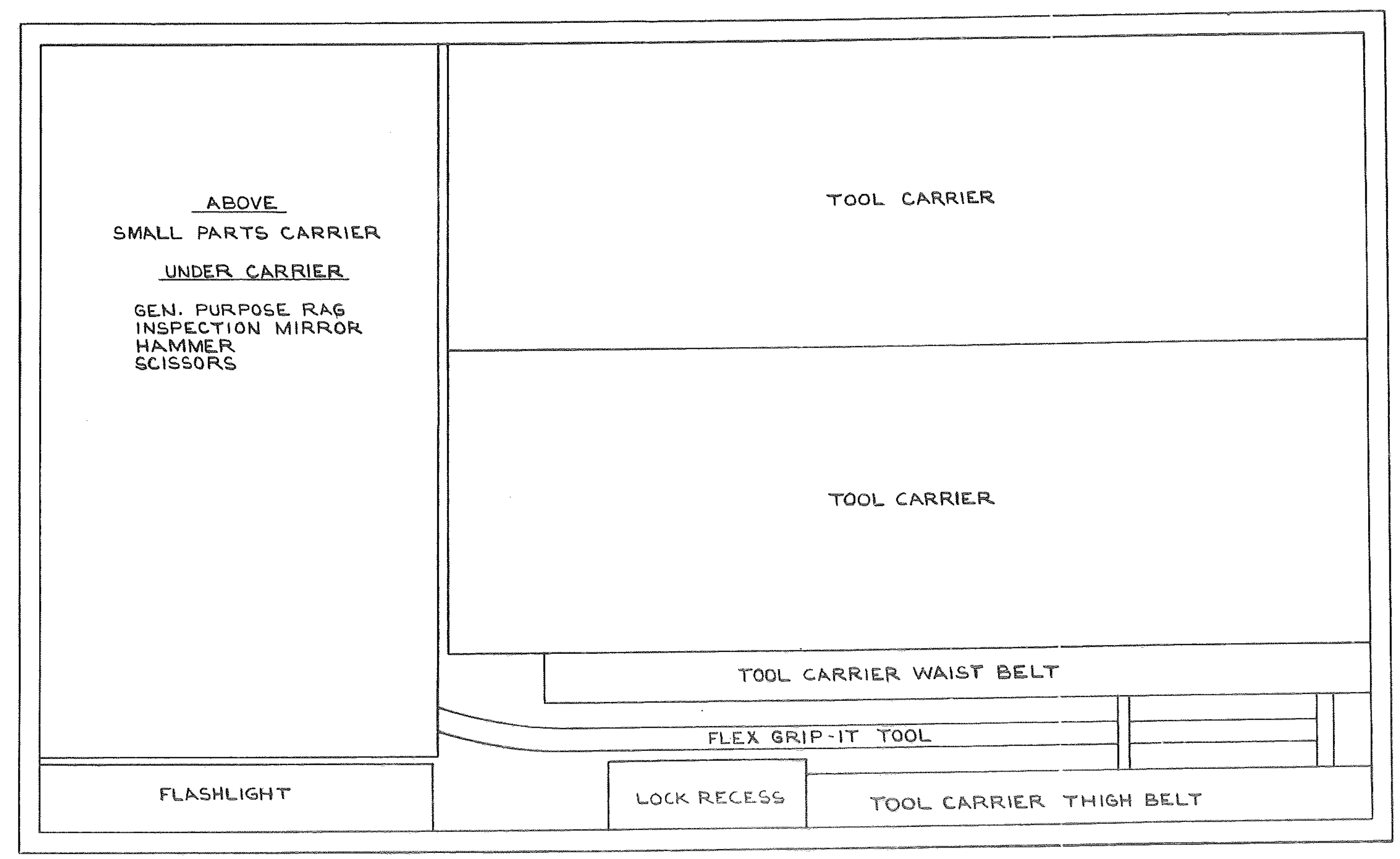
ASTRONAUT TOOL KIT
DRAWER No.3 LAYOUT

SIZE	CODE IDENT NO.	
D	04236	RES-31655
SCALE FULL	M. HUSSEY	SHEET

DEN 081807-01 (10-66)

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED

NOTES:
1. SECURE ITEMS IN DRAWER WITH VELCRO

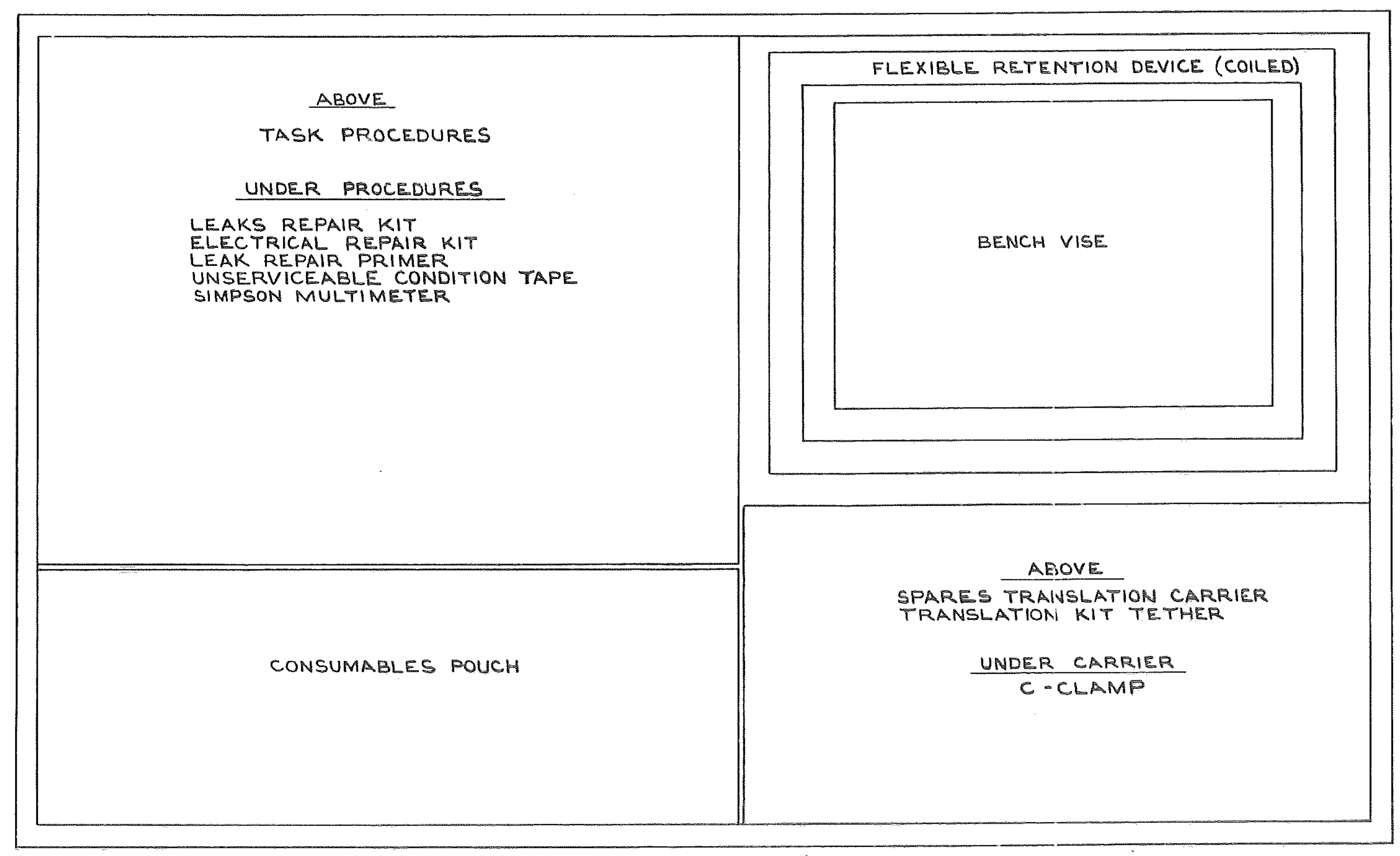


ASTRONAUT TOOL KIT
DRAWER No. 4 LAYOUT

SIZE	CODE IDENT NO.	
D	04236	RES-31656
SCALE FULL	M. HUSSEY	SHEET

10

NOTES:
1. SECURE ITEMS IN DRAWER WITH VELCRO

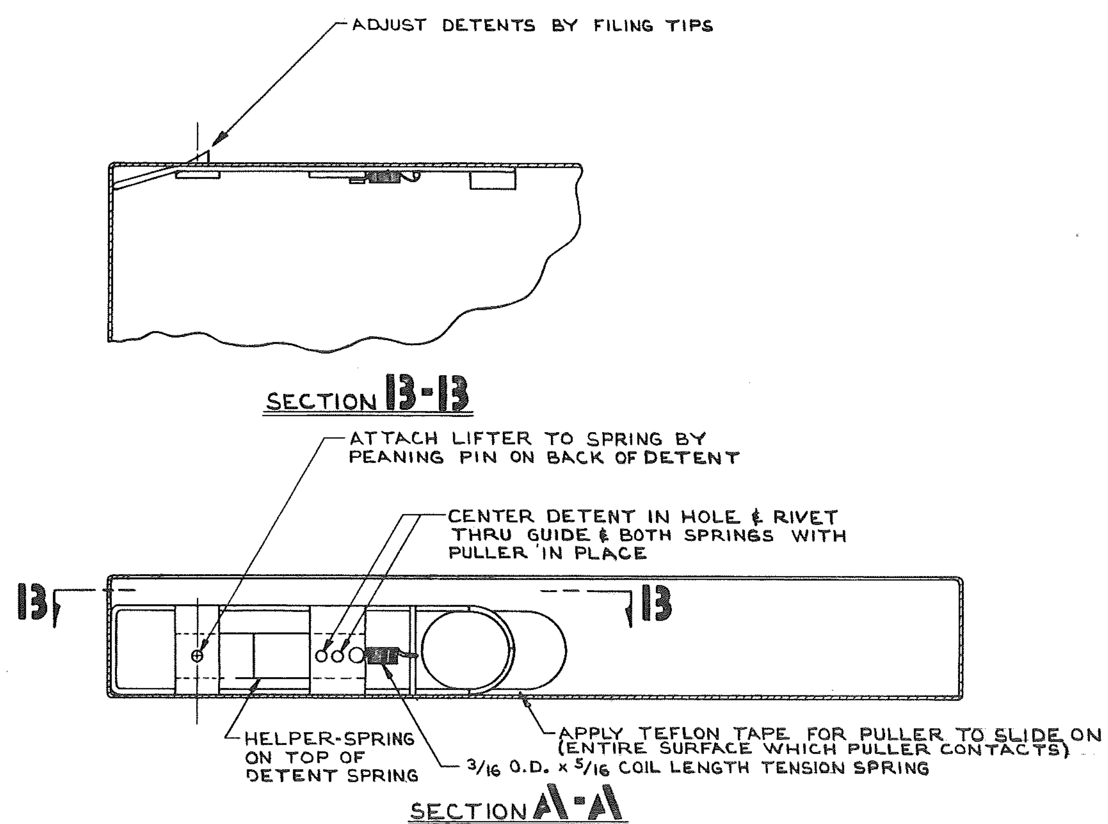


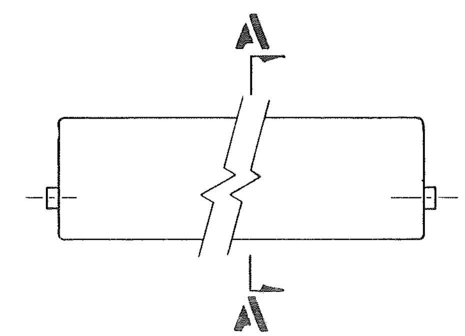
ASTRONAUT TOOL KIT
DRAWER No. 5 LAYOUT

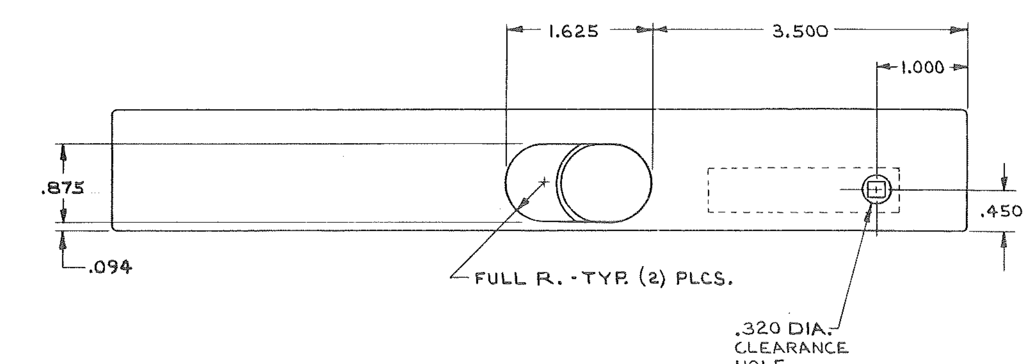
SIZE	CODE IDENT NO.	
D	04236	RES-31657
SCALE FULL	M. HUSSEY	SHEET

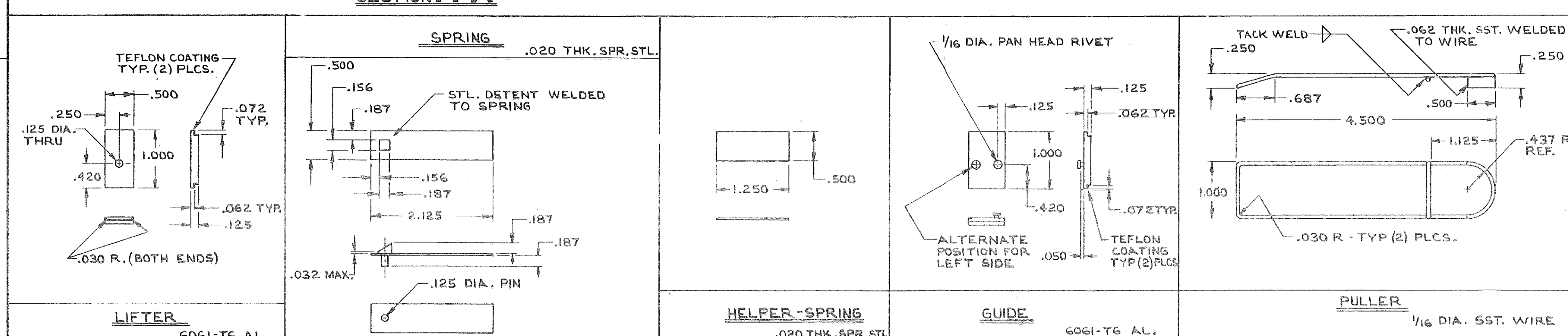
11

NOTES:
1. SHEET 1 OF THIS DRAWING SHOWS DETENT DETAILS FOR DRAWERS 2 & 3 WITH COMPLETE DETAILS OF ALL PARTS. SHEET 2 SHOWS ONLY THAT INFORMATION NECESSARY TO APPLY THE SYSTEM TO DRAWERS 4 & 5. SHEET 3 DOES THE SAME FOR DRAWER No. 1. WHEN PARTS VARY ONLY THE DIMENSIONS THAT VARY ARE GIVEN.
2. ALL TOLERANCES TO BE ±.010
3. BREAK ALL SHARP EDGES









ASTRONAUT TOOL KIT
DETENT DETAILS
DRAWERS 2 & 3

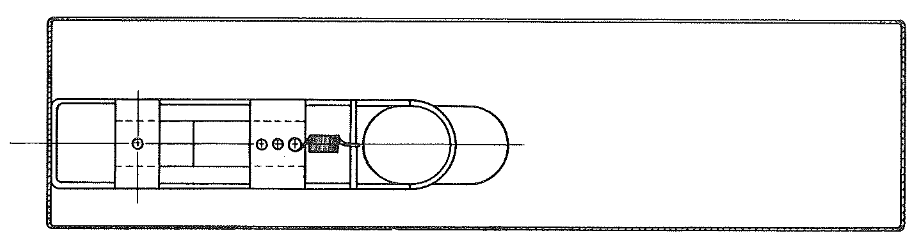
1/18/71

SIZE	CODE IDENT NO.	
D	04236	RES-31658
SCALE FULL	M. HUSSEY	SHEET 1 OF 3

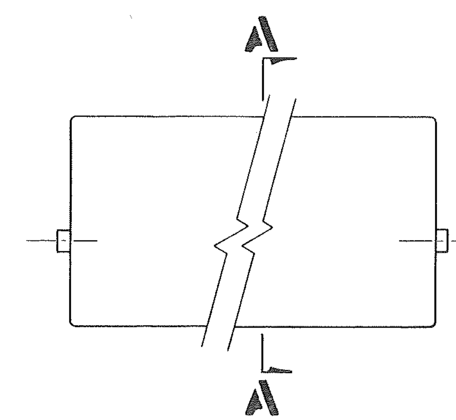
DEH 061607-01 (10-68)

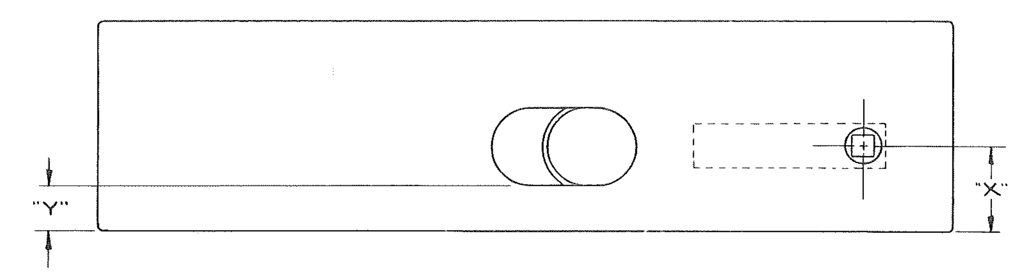
REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED

(OTHER DIMENSIONS ¢ INSTRUCTIONS SAME AS SHEET 1)



SECTION A-A

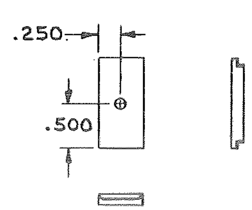




DRAWER NUMBER	DIMENSION "X"	DIMENSION "Y"
4	.950	.512
5	1.950	1.512

LIFTER

(OTHER DIMENSIONS SAME AS SHEET 1)



SPRING

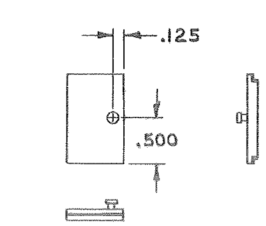
(SAME AS SHOWN ON SHEET 1)

HELPER-SPRING

(SAME AS SHEET 1)

GUIDE

(OTHER DIMENSIONS SAME AS SHEET 1)



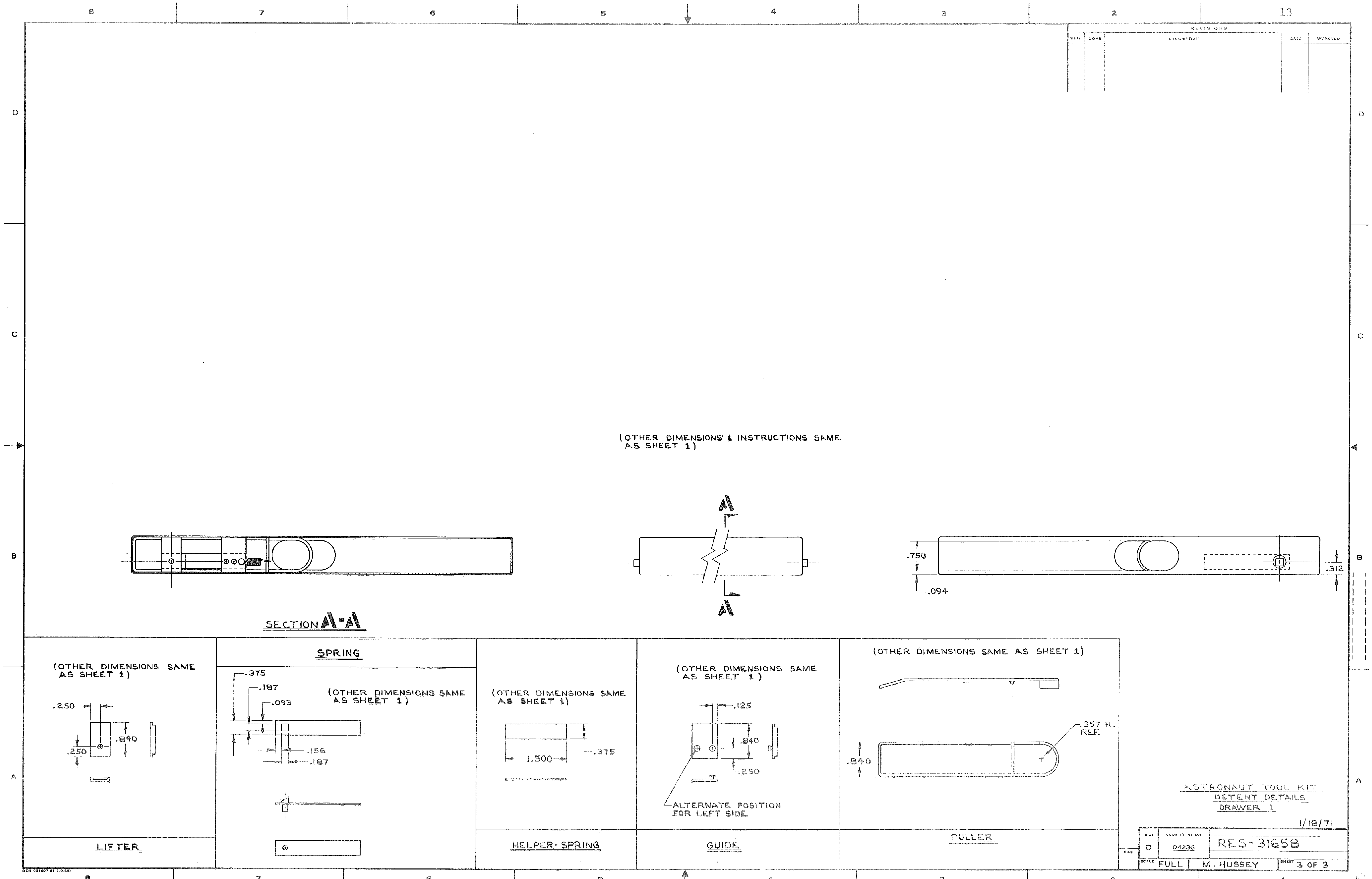
PULLER

(SAME AS SHEET 1)

ASTRONAUT TOOL KIT
DETENT DETAILS
DRAWERS 4 & 5

1/18/71

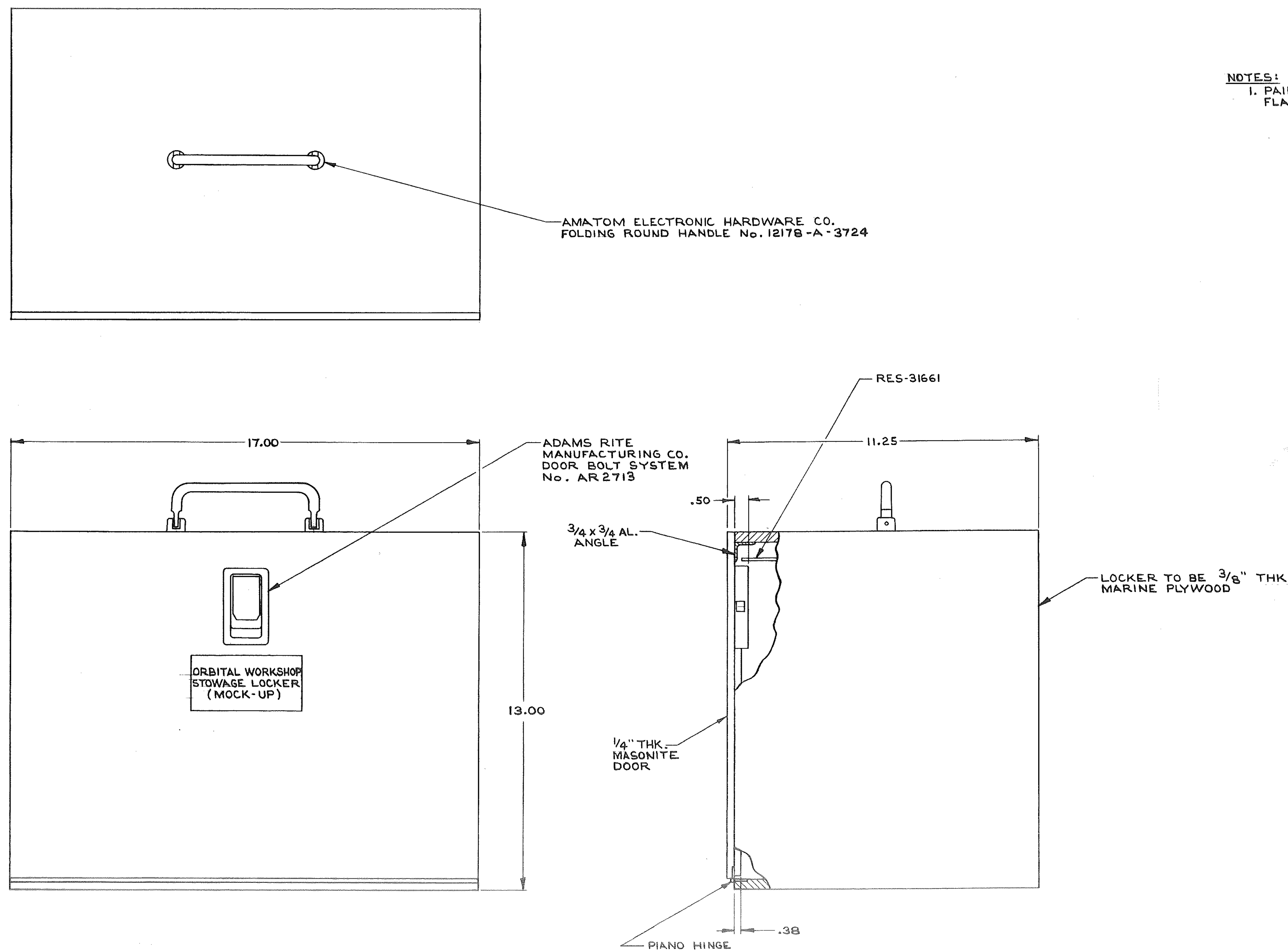
SIZE	CODE IDENT NO.	
D	04:36	RES-31658
SCALE FULL	M. HUSSEY	SHEET 2 OF 3


REVISIONS
SYM ZONE DESCRIPTION DATE APPROVED
(OTHER DIMENSIONS & INSTRUCTIONS SAME AS SHEET 1)
A
A
.750
.094
.312
SECTION A-A
LIFTER
(OTHER DIMENSIONS SAME AS SHEET 1)
.250
.250
.840
SPRING
(OTHER DIMENSIONS SAME AS SHEET 1)
.375
.187
.093
.156
.187
HELPER-SPRING
(OTHER DIMENSIONS SAME AS SHEET 1)
1.500
.375
GUIDE
(OTHER DIMENSIONS SAME AS SHEET 1)
.125
.840
.250
ALTERNATE POSITION FOR LEFT SIDE
PULLER
(OTHER DIMENSIONS SAME AS SHEET 1)
.357 R. REF.
.840
ASTRONAUT TOOL KIT
DETENT DETAILS
DRAWER 1
1/18/71
SIZE D
CODE IDENT NO. 04236
RES-31658
SCALE FULL
M. HUSSEY
SHEET 3 OF 3

REVISIONS

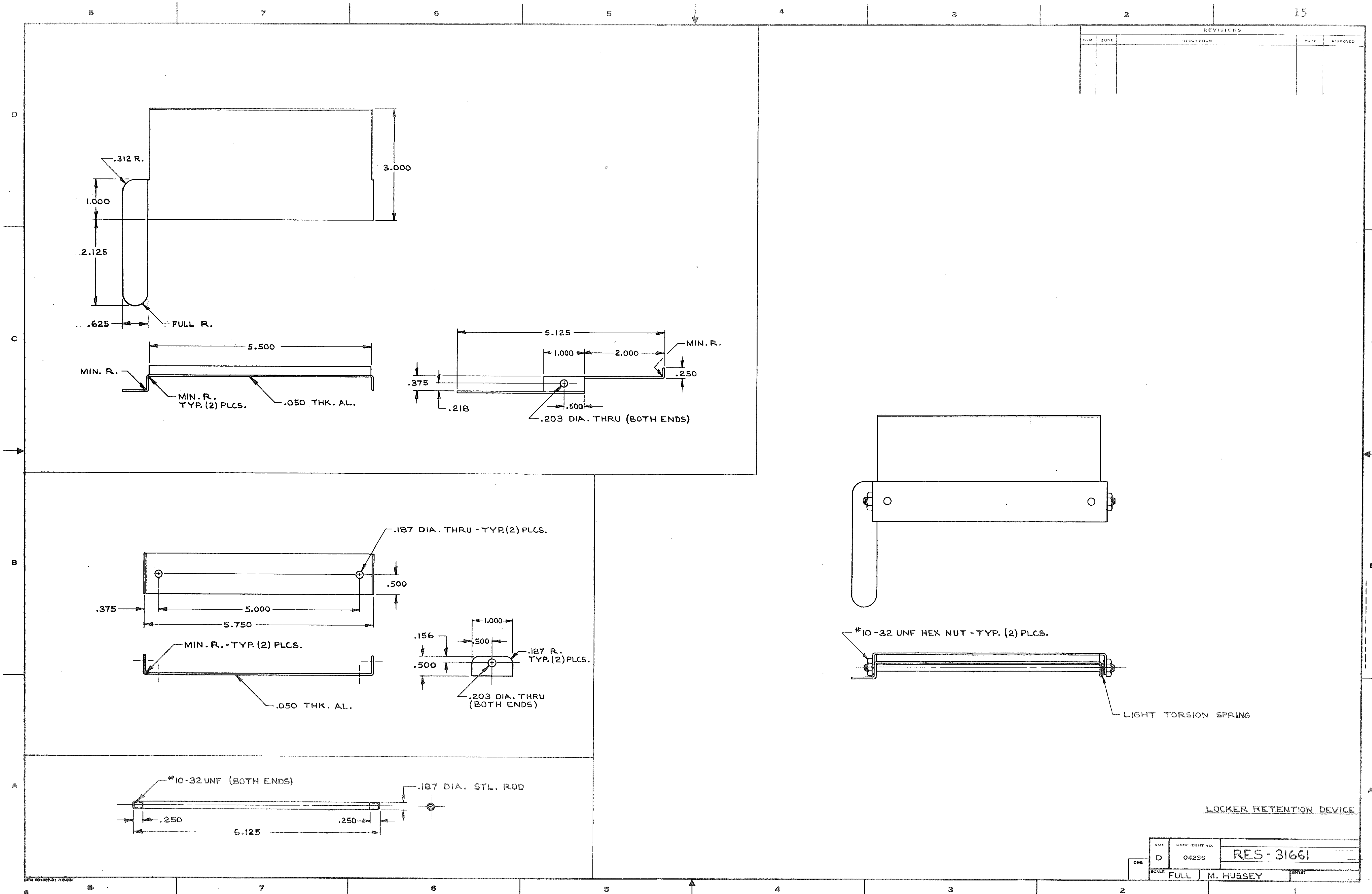
SYM	ZONE	DESCRIPTION	DATE	APPROVED

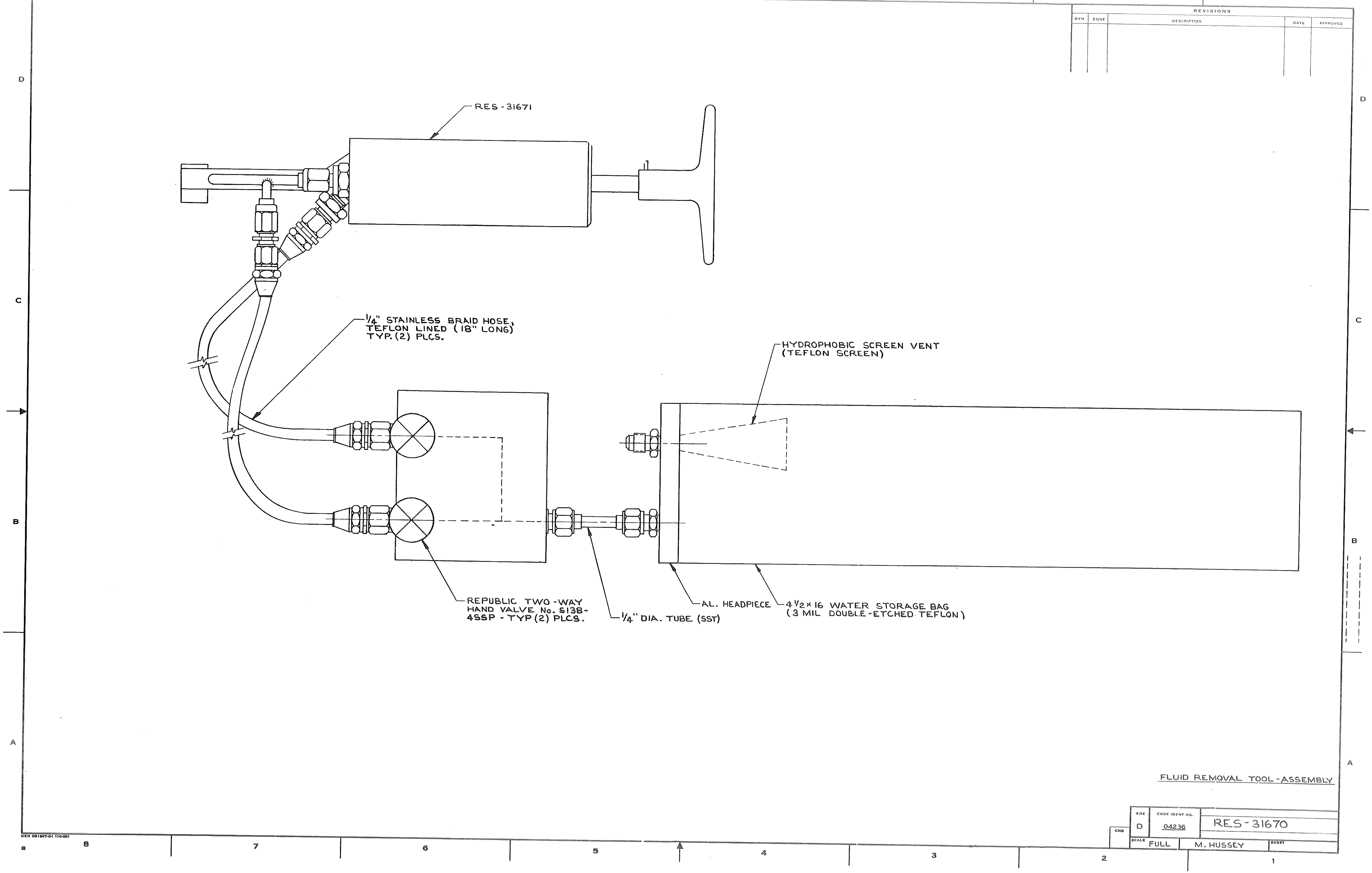
NOTES:
1. PAINT INSIDE & OUTSIDE WITH FLAT GRAY ENAMEL



STOWAGE LOCKER MOCK-UP

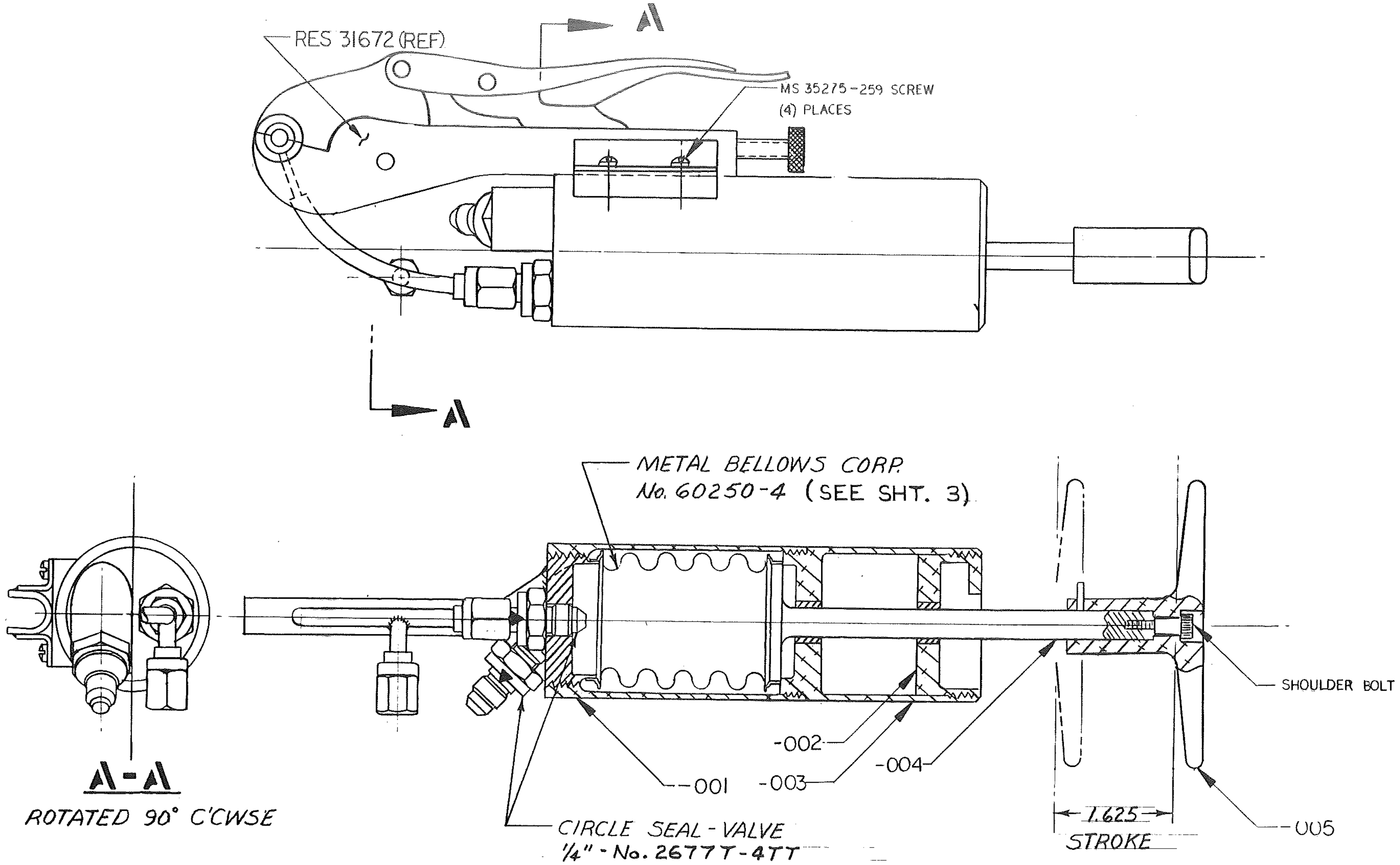
SIZE	CODE IDENT NO.	
D	04236	RES-31660
SCALE 1/2" = 1"	M. HUSSEY	SHEET


REVISIONS
SYM
ZONE
DESCRIPTION
DATE
APPROVED
.312 R.
1.000
2.125
.625
FULL R.
3.000
5.500
MIN. R.
MIN. R.
TYP. (2) PLCS.
.050 THK. AL.
5.125
1.000
2.000
MIN. R.
.250
.375
.218
.500
.203 DIA. THRU (BOTH ENDS)
.187 DIA. THRU - TYP. (2) PLCS.
.500
.375
5.000
5.750
MIN. R. - TYP. (2) PLCS.
.050 THK. AL.
1.000
.156
.500
.500
.187 R.
TYP. (2) PLCS.
.203 DIA. THRU
(BOTH ENDS)
#10-32 UNF (BOTH ENDS)
.187 DIA. STL. ROD
.250
.250
6.125
#10-32 UNF HEX NUT - TYP. (2) PLCS.
LIGHT TORSION SPRING
LOCKER RETENTION DEVICE
SIZE
D
CODE IDENT NO.
04236
RES - 31661
SCALE
FULL
M. HUSSEY
SHEET


REVISIONS
SYM
ZONE
DESCRIPTION
DATE
APPROVED
RES - 31671
1/4" STAINLESS BRAID HOSE, TEFLON LINED (18" LONG) TYP. (2) PLCS.
HYDROPHOBIC SCREEN VENT (TEFLON SCREEN)
REPUBLIC TWO-WAY HAND VALVE No. S138-4SSP - TYP (2) PLCS.
1/4" DIA. TUBE (SST)
AL. HEADPIECE
4 1/2 x 16 WATER STORAGE BAG (3 MIL DOUBLE-ETCHED TEFLON)
FLUID REMOVAL TOOL-ASSEMBLY
SIZE D
CODE IDENT NO. 04236
RES-31670
SCALE FULL
M. HUSSEY
SHEET

REVISIONS

SYM.	ZONE	DESCRIPTION	DATE	APPROVED



LIST OF MATERIAL

QUANTITY / DASH NO.		PART NO.	ZONE	SER. STR.	DESCRIPTION	STOCK SIZE	MATERIAL OR VENDOR	ISSUE COND.	MATERIAL SPECIFICATION	FINISH OR MFR. CODE	CHG.
ODD DASH NO. SHOWN	EVEN DASH NO. OPP.										

DIMENSIONING REF. MIL-STD-8
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES AND ARE AFTER PLATING
TOLERANCES ON:

FRACTIONS	DECIMALS .X	.XX	.XXX	ANGLES
± 1/32	± .1	± .03	± .010	± 1/2°

MACHINED SURFACES
REF. - MIL-STD-10 √

MIL-I-8500 STATUS
INTERCHANGEABLE
REPLACEABLE
UNCONTROLLED

DRAWN BY T. JONKONIEC DEPT. 1640 DATE 1-19-71
CHECKER
STRESS ENGR.
WT. ENGR.
MATL. ENGR.
RELIABILITY
GR. ENGR.
PROJECT
CUST. REF.

CALC. WT.	DASH NUMBER	NEXT ASSY.	USED ON	FINAL ASSY.	TEST
		APPLICATION		QTY. REQD.	

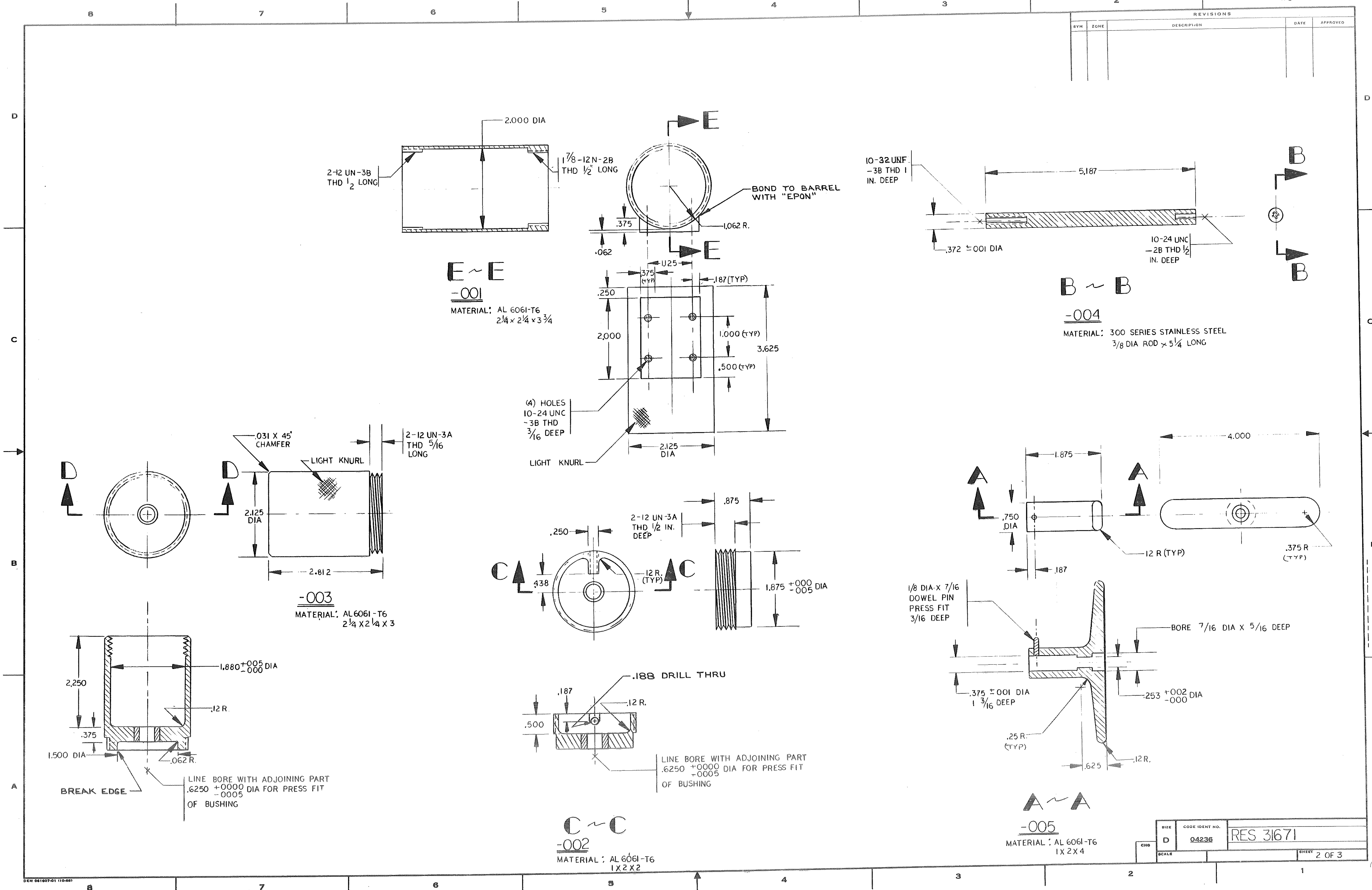
EFFECTIVE ON

MARTIN MARIETTA CORPORATION
AEROSPACE GROUP
Friendship International Airport, Maryland

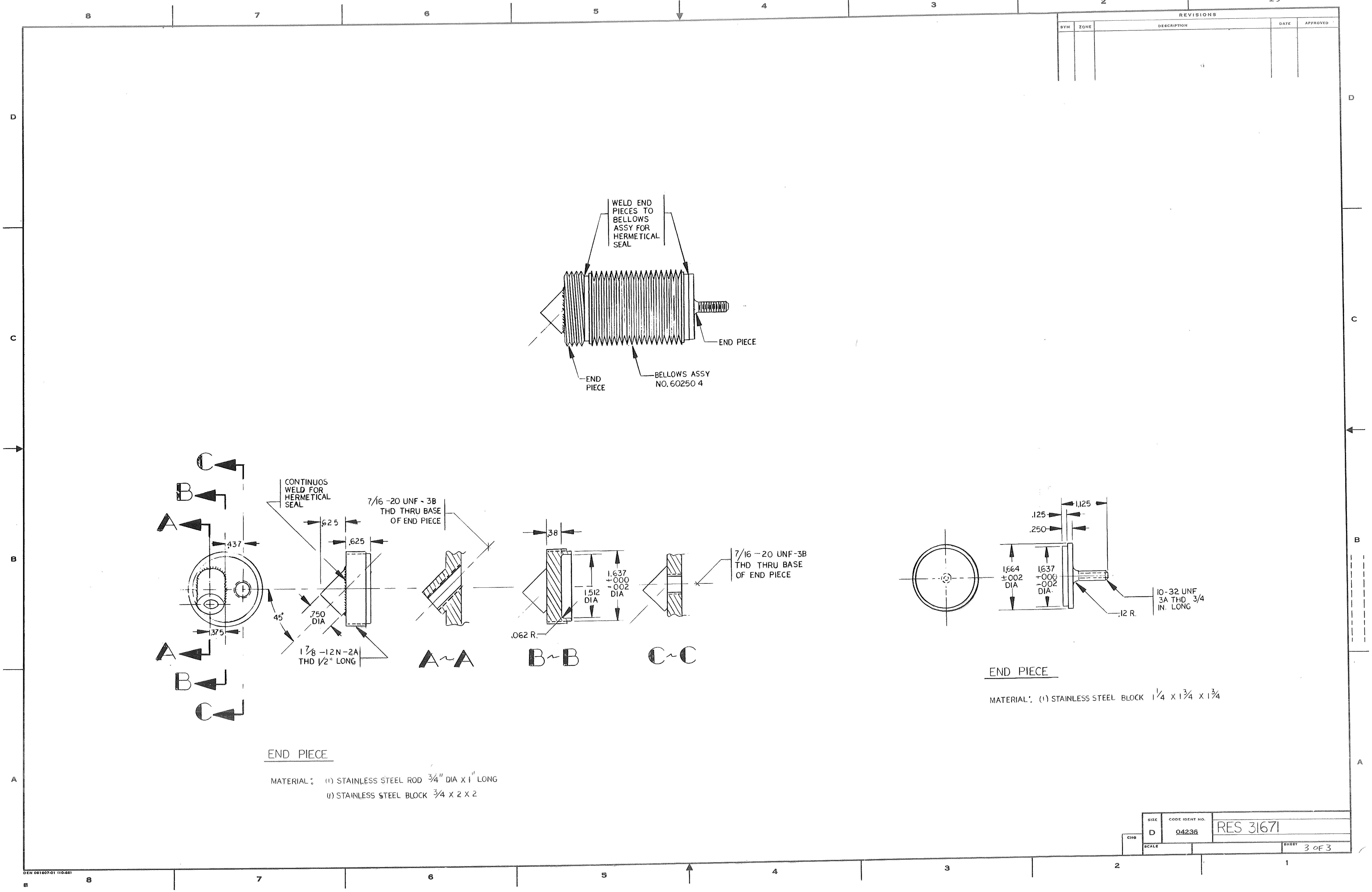
FLUID REMOVAL PUMP

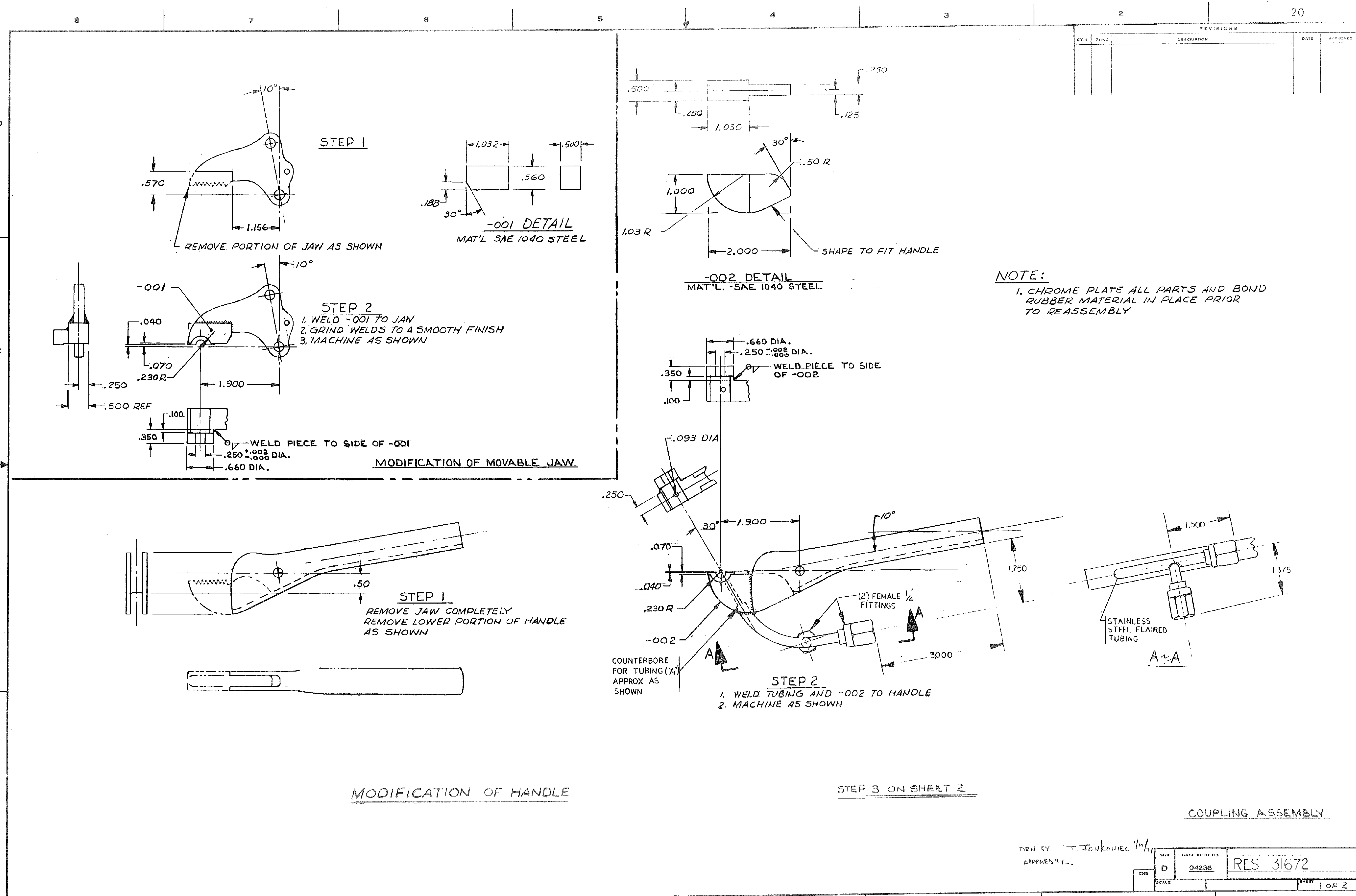
SIZE D | CODE IDENT. NO. 38597 | RES 31671

SCALE | SHEET 1 OF 3

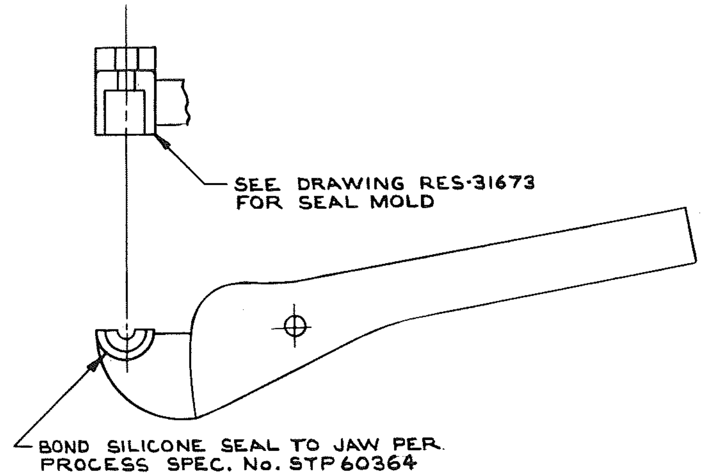


REVISIONS
SYM ZONE DESCRIPTION DATE APPROVED
2.000 DIA
2-12 UN-3B THD 1/2 LONG
1 7/8-12N-2B THD 1/2" LONG
E ~ E
-001
MATERIAL: AL 6061-T6 2 1/4 x 2 1/4 x 3 3/4
BOND TO BARREL WITH "EPON"
1.062 R.
.375
.062
1.125
.375 (TYP)
.187 (TYP)
.250
2.000
1.000 (TYP)
.500 (TYP)
3.625
(4) HOLES 10-24 UNC -3B THD 3/16 DEEP
LIGHT KNURL
2.125 DIA
10-32 UNF -3B THD 1 IN. DEEP
5.187
.372 ± .001 DIA
10-24 UNC -2B THD 1/2 IN. DEEP
B ~ B
-004
MATERIAL: 300 SERIES STAINLESS STEEL 3/8 DIA ROD x 5 1/4 LONG
.031 X 45° CHAMFER
LIGHT KNURL
2-12 UN-3A THD 5/16 LONG
2.125 DIA
2.812
-003
MATERIAL: AL 6061-T6 2 1/4 x 2 1/4 x 3
.875
2-12 UN-3A THD 1/2 IN. DEEP
.250
.438
.12 R. (TYP)
1.875 +.000 -.005 DIA
4.000
1.875
.750 DIA
.187
.12 R (TYP)
.375 R (TYP)
1/8 DIA x 7/16 DOWEL PIN PRESS FIT 3/16 DEEP
BORE 7/16 DIA X 5/16 DEEP
.375 ± .001 DIA 1 3/16 DEEP
.253 +.002 -.000 DIA
.25 R (TYP)
.625
.12 R.
A ~ A
-005
MATERIAL: AL 6061-T6 1 X 2 X 4
2.250
1.880 +.005 -.000 DIA
.12 R.
.375
1.500 DIA
.062 R.
BREAK EDGE
LINE BORE WITH ADJOINING PART .6250 +.0000 -.0005 DIA FOR PRESS FIT OF BUSHING
.188 DRILL THRU
.187
.12 R.
.500
LINE BORE WITH ADJOINING PART .6250 +.0000 -.0005 DIA FOR PRESS FIT OF BUSHING
C ~ C
-002
MATERIAL: AL 6061-T6 1 X 2 X 2
SIZE D
CODE IDENT NO. 04236
RES 31671
SCALE
SHEET 2 OF 3

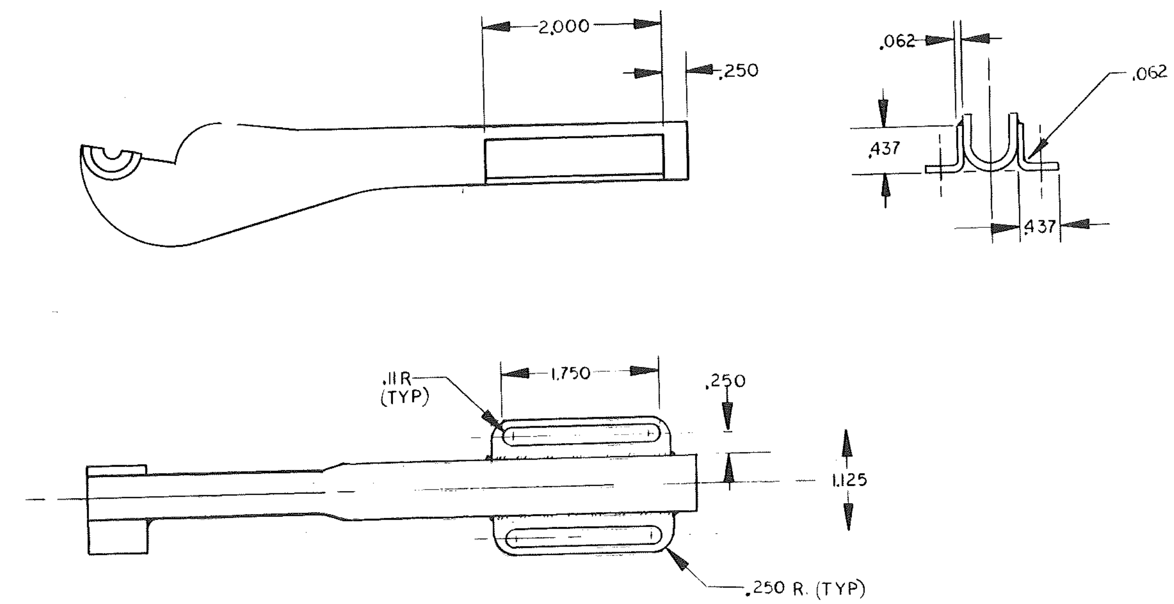

REVISIONS
SYM
ZONE
DESCRIPTION
DATE
APPROVED
WELD END PIECES TO BELLOWS ASSY FOR HERMETICAL SEAL
END PIECE
BELLOWS ASSY NO. 60250 4
END PIECE
CONTINUOS WELD FOR HERMETICAL SEAL
7/16 -20 UNF - 3B THD THRU BASE OF END PIECE
.625
.625
.437
.750 DIA
45°
.375
1 7/8 -12N-2A THD 1/2" LONG
A~A
.38
1.512 DIA
1.637 +.000 -.002 DIA
.062 R.
B~B
7/16 -20 UNF-3B THD THRU BASE OF END PIECE
C~C
END PIECE
MATERIAL: (1) STAINLESS STEEL ROD 3/4" DIA X 1" LONG
(1) STAINLESS STEEL BLOCK 3/4 X 2 X 2
.125
.250
1.125
1.664 ±.002 DIA
1.637 +.000 -.002 DIA.
10-32 UNF 3A THD 3/4 IN. LONG
.12 R.
END PIECE
MATERIAL: (1) STAINLESS STEEL BLOCK 1 1/4 X 1 3/4 X 1 3/4
SIZE
D
CODE IDENT NO.
04236
RES 31671
SCALE
SHEET
3 OF 3
CHG
DEN 061607-01 (10-66)


REVISIONS
SYM | ZONE | DESCRIPTION | DATE | APPROVED
STEP 1
REMOVE PORTION OF JAW AS SHOWN
.570
1.156
10°
-001 DETAIL
MAT'L SAE 1040 STEEL
1.032
.560
.500
.188
30°
STEP 2
1. WELD -001 TO JAW
2. GRIND WELDS TO A SMOOTH FINISH
3. MACHINE AS SHOWN
-001
.040
.070
.230 R
1.900
.250
.500 REF
.100
.350
WELD PIECE TO SIDE OF -001
.250 +.002 -.000 DIA.
.660 DIA.
MODIFICATION OF MOVABLE JAW
.500
.250
1.030
.125
.250
30°
.50 R
1.000
1.03 R
2.000
SHAPE TO FIT HANDLE
-002 DETAIL
MAT'L. -SAE 1040 STEEL
NOTE:
1. CHROME PLATE ALL PARTS AND BOND RUBBER MATERIAL IN PLACE PRIOR TO REASSEMBLY
.660 DIA.
.250 +.002 -.000 DIA.
WELD PIECE TO SIDE OF -002
.350
.100
.093 DIA
.250
30°
1.900
10°
.070
.040
.230 R
-002
COUNTERBORE FOR TUBING (1/4) APPROX AS SHOWN
(2) FEMALE 1/4" FITTINGS
1.750
3.000
STEP 2
1. WELD TUBING AND -002 TO HANDLE
2. MACHINE AS SHOWN
1.500
1.375
STAINLESS STEEL FLAIRED TUBING
A-A
.50
STEP 1
REMOVE JAW COMPLETELY
REMOVE LOWER PORTION OF HANDLE AS SHOWN
MODIFICATION OF HANDLE
STEP 3 ON SHEET 2
COUPLING ASSEMBLY
DRN BY. T. JONKONIEC 1/10/71
APPROVED BY
SIZE D
CODE IDENT NO. 04236
RES 31672
SHEET 1 OF 2

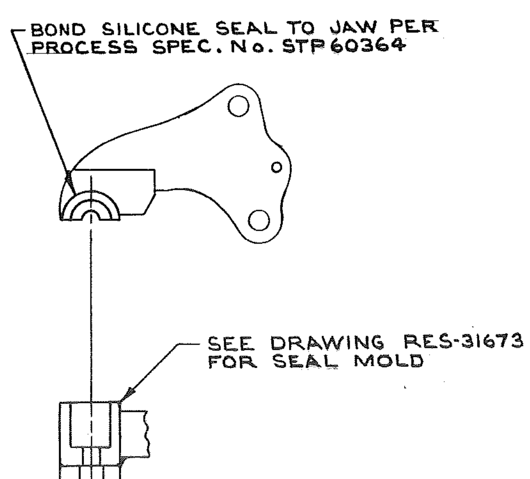
SYM	ZONE	DESCRIPTION	DATE	APPROVED
REVISIONS				



STEP 3



STEP 4. ATTACH ANGLE WELDMENT



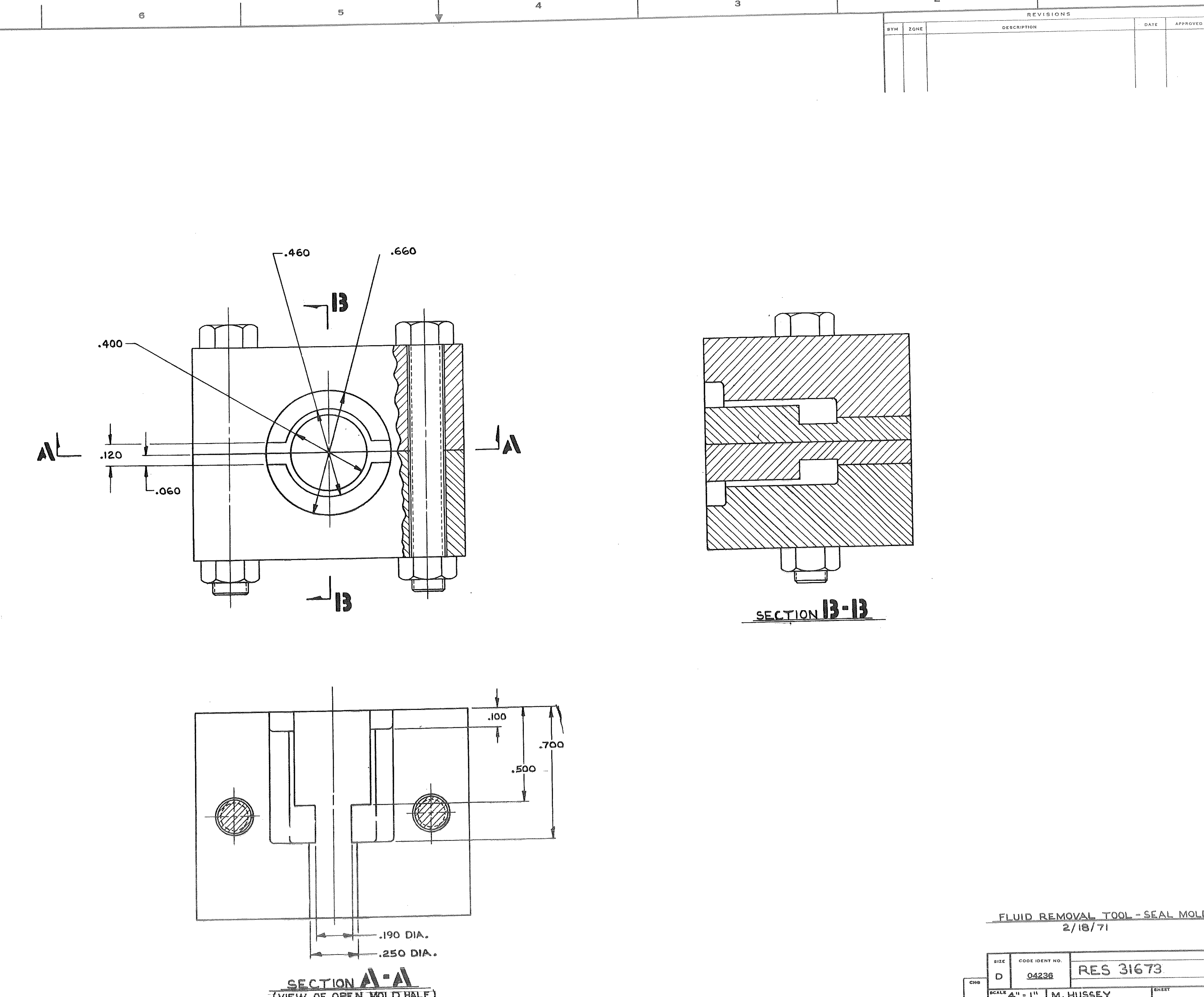
INSTALLATION OF SEAL
TO MOVABLE JAW

STEP 5. REASSEMBLE VISEGRIP

COUPLING ASSEMBLY

SIZE	CODE IDENT NO.	
D	04236	RES 31672
SCALE		SHEET 2 OF 2

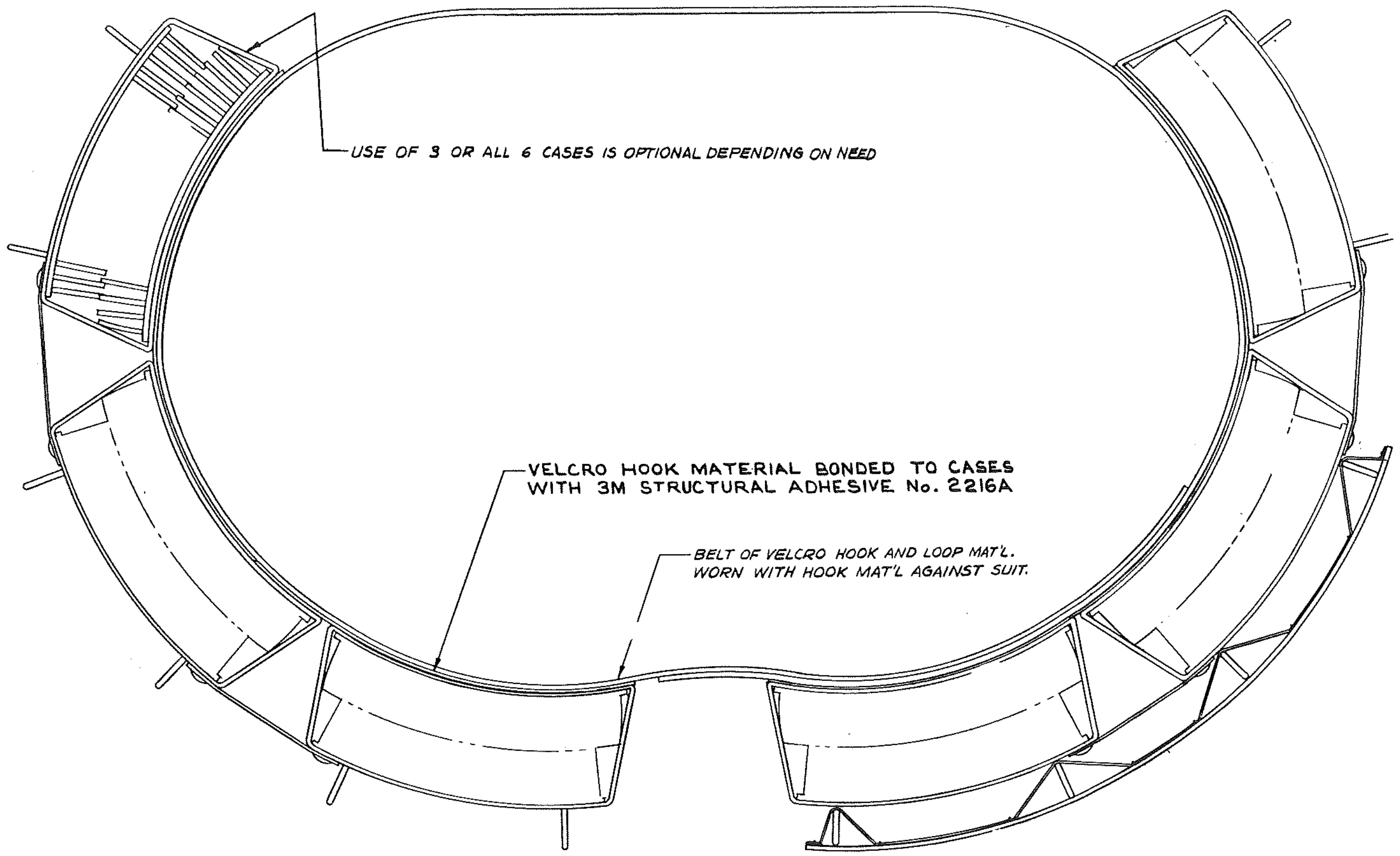
GEN 061607-01 (10-68)

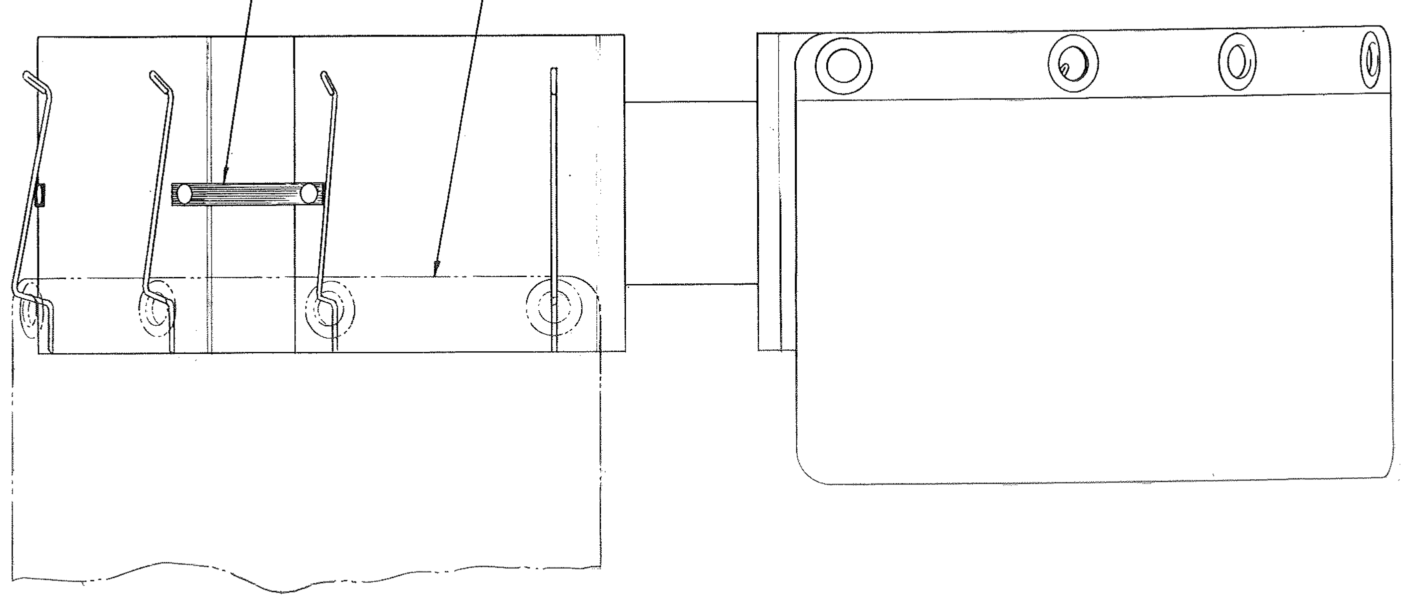


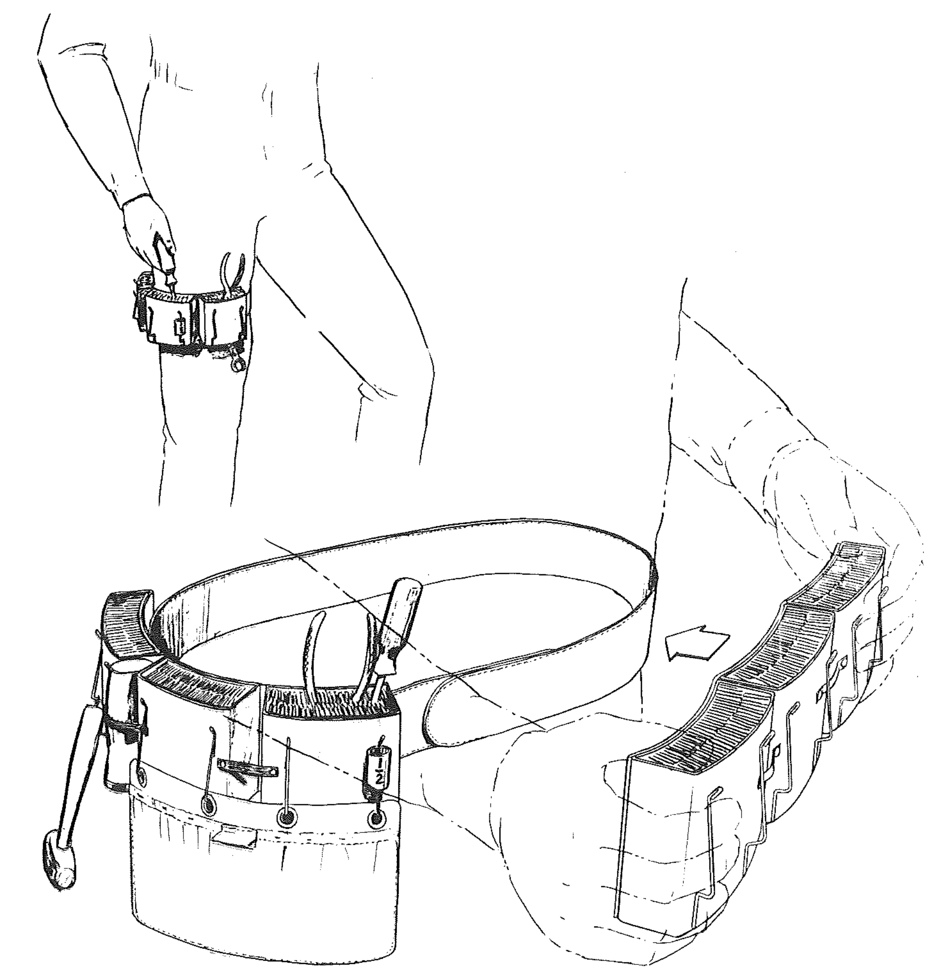
FLUID REMOVAL TOOL - SEAL MOLD
2/18/71

SIZE	CODE IDENT NO.	
D	04236	RES 31673
SCALE 4" = 1"	M. HUSSEY	SHEET 1

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED







RES 31664

MARTIN MARIETTA CORP. DENVER DIVISION R.C. 12/16/70

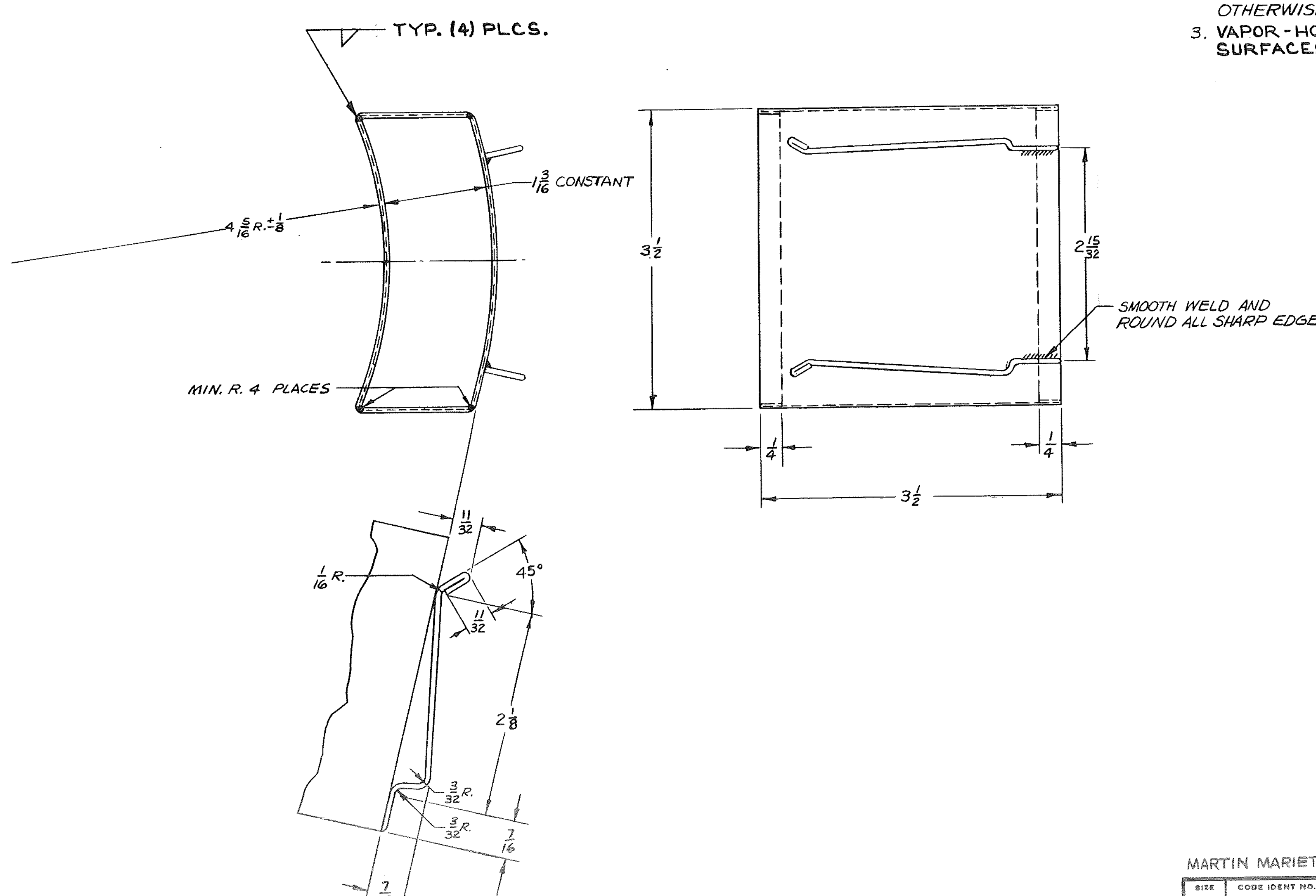
SIZE	CODE IDENT NO.	
D	04236	ASTRONAUT TOOL CARRIER ASSEMBLY
SCALE	RES-31680	SHEET

DEN 061607-01 (10-68)

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED

NOTES:

1. MAT'L: SPRING CLIPS - 17-4 PH .06 DIA. STAINLESS STEEL WIRE. HEAT TREAT WIRE BEFORE WELDING. CASE - 301 OR 303 ANNEALED STAINLESS STEEL, .020 THICKNESS.
2. TOLERANCE ± 1/32 EXCEPT WHERE OTHERWISE NOTED.
3. VAPOR-HONE FINISH ON EXTERIOR SURFACES



MARTIN MARIETTA CORP. DENVER DIVISION 12/18/70 R.C.

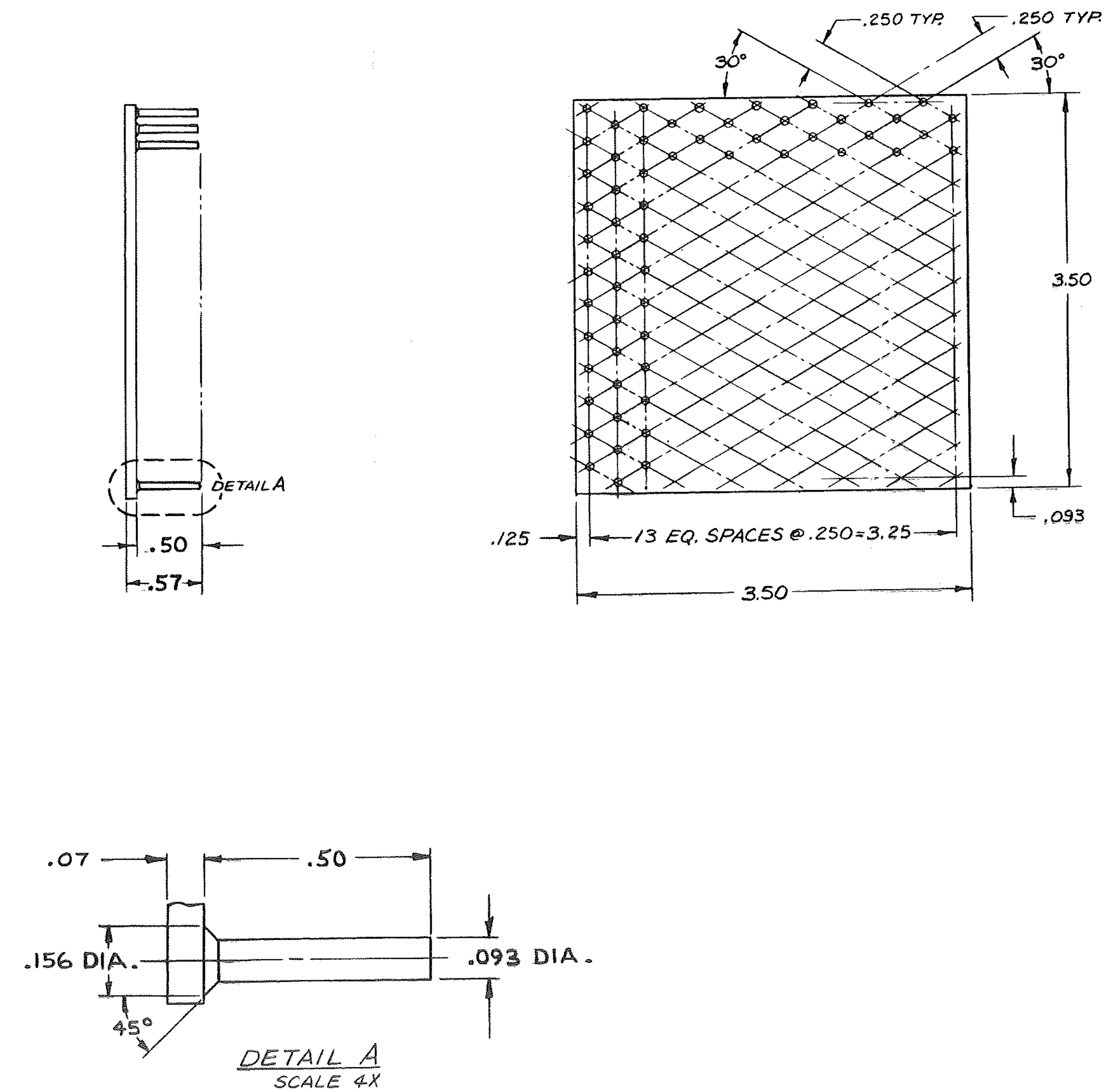
SIZE	CODE IDENT NO.	
C	04236	ASTRONAUT TOOL CARRIER, CASE
SCALE FULL	RES - 31681	SHEET

CHG

RES-31661

DEN 081608-01 (2-69)

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED



DETAIL A
SCALE 4X

NOTES:

1. MAT'L. - ADIPRENE-100, URETHANE
2. BRUSH ASSY. TO BE BONDED TO CASE ASSY. (RES-31681) WITH EITHER ADIPRENE-100 OR CREST PRODUCTS CO. ADHESIVE No. 7343
3. TOLERANCE - .000 = ±.010
   .00 = ±.02
4. COLOR - WHITE

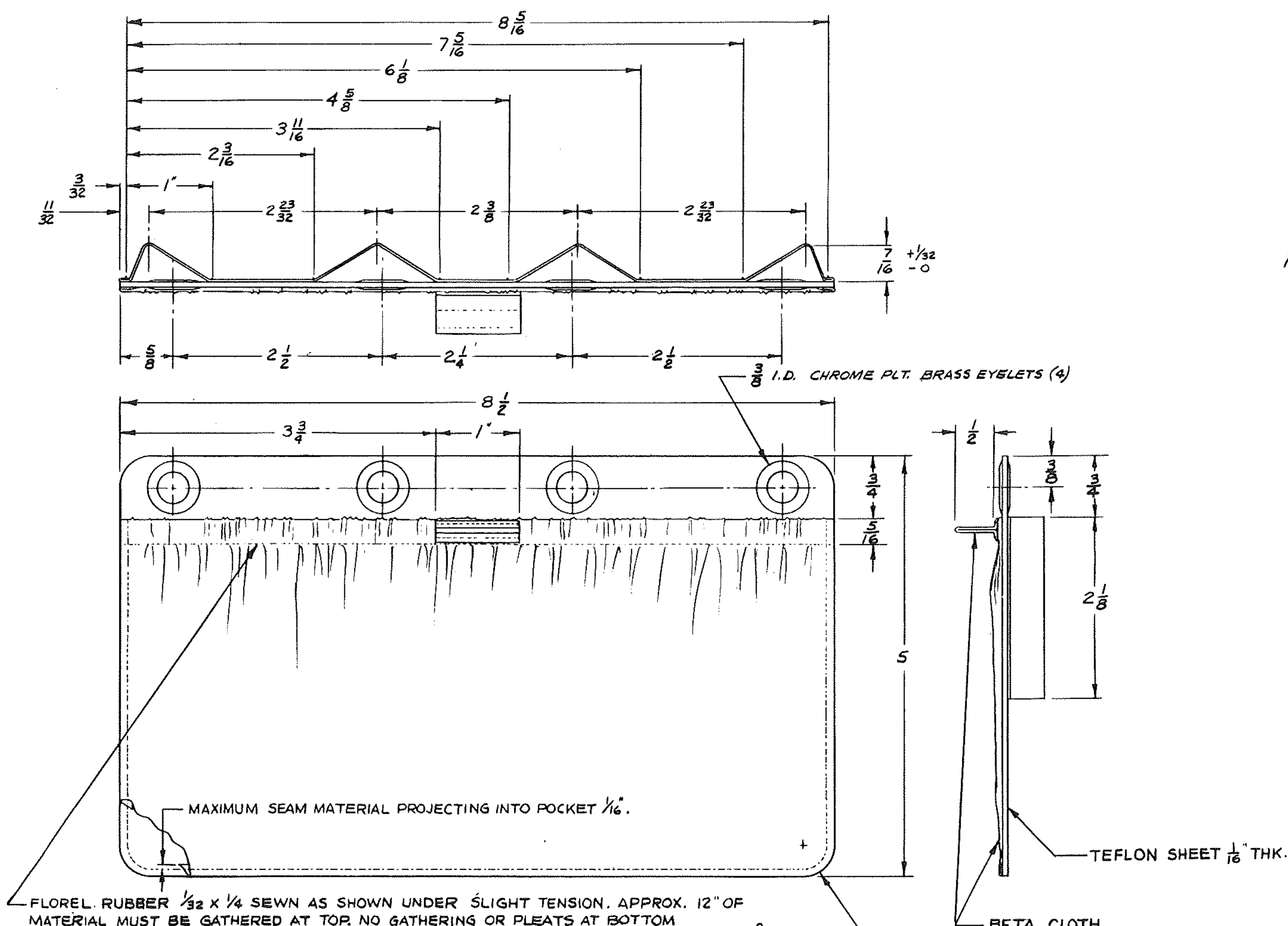
RES-31665

MARTIN MARIETTA CORP. DENVER DIVISION R.CHURCH 12/18/7[illegible]

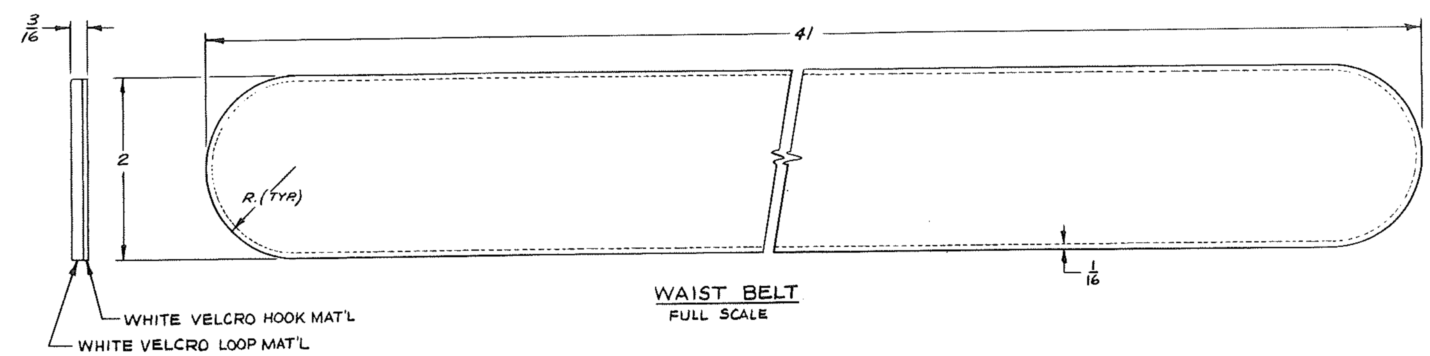
SIZE	CODE IDENT NO.	
C	04236	ASTRONAUT TOOL CARRIER, BRUSH
SCALE FULL	RES-31682	SHEET

CHG

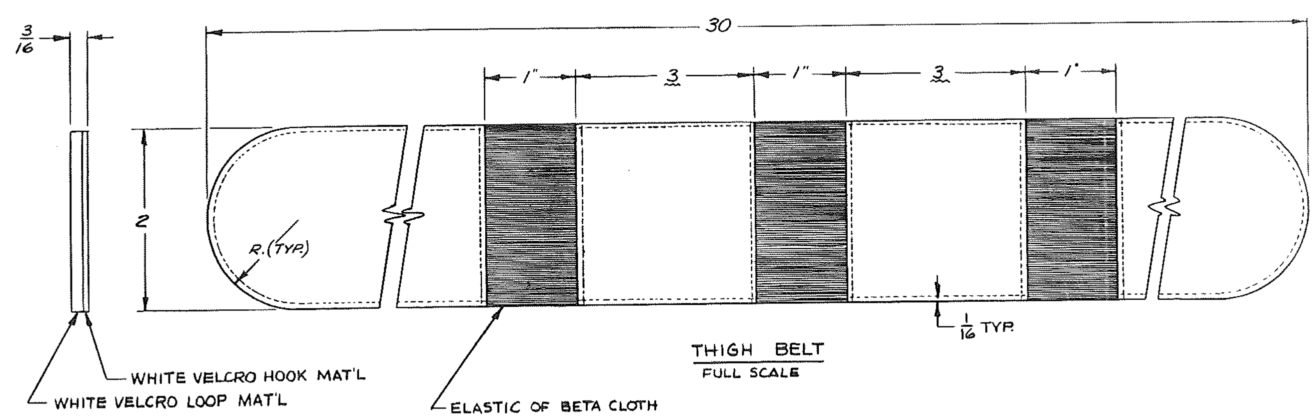
DEN 061605-01 (2-69)



SMALL PARTS CONTAINER
FULL SCALE



WAIST BELT
FULL SCALE



THIGH BELT
FULL SCALE

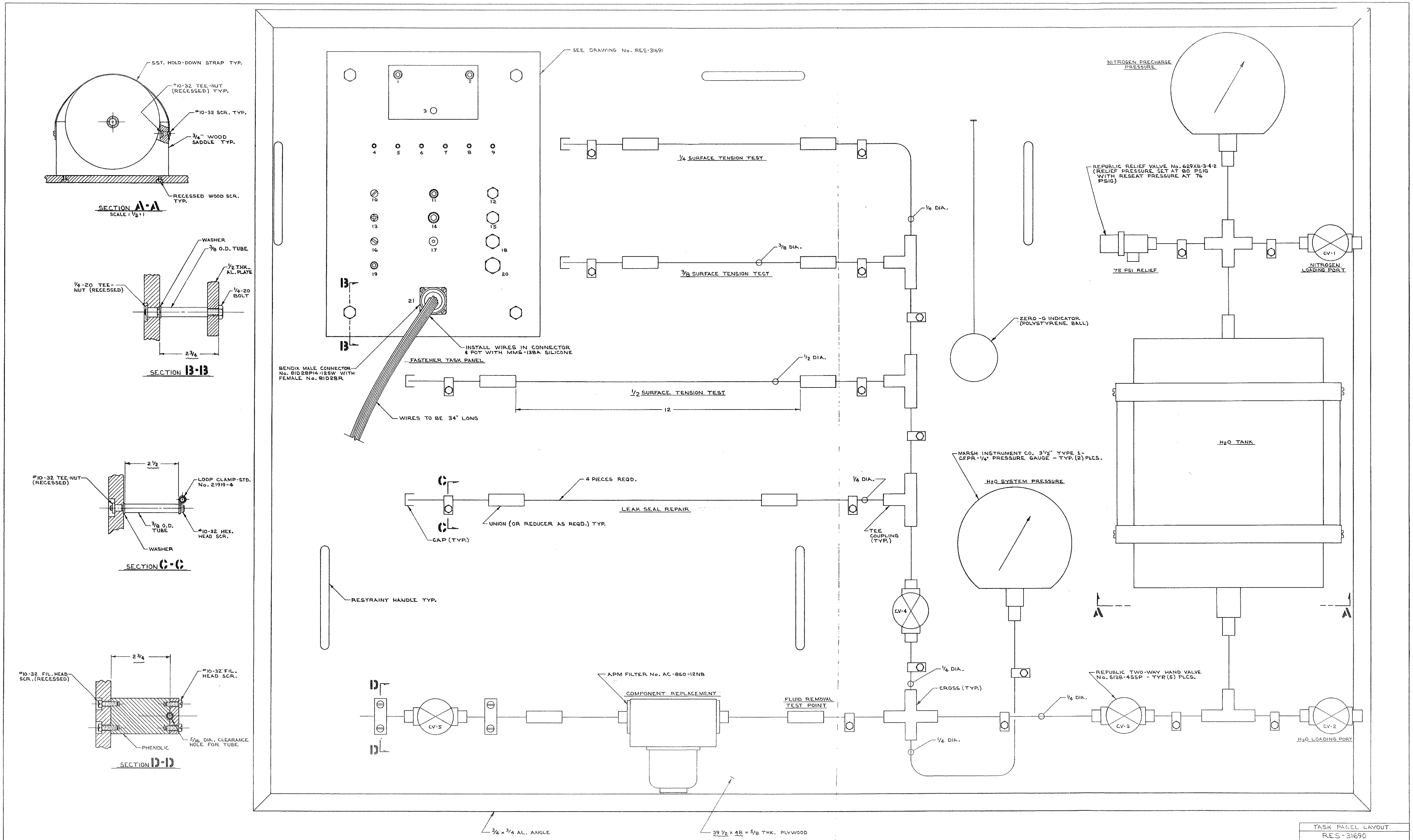
NOTES FOR ALL ASSEMBLIES SHOWN:

1. SEWING AND ALL PIECES MUST BE STRAIGHT AND HAVE NEAT OVERALL APPEARANCE.
2. THREAD MAT'L, ASS'Y TECHNIQUES AND TOLERANCE MAY BE VARIED CONSISTANT WITH GOOD INDUSTRY PRACTICES AND WITH MMC APPROVAL.
3. ALL MATERIALS SUPPLIED BY MMC.
4. ALL MATERIALS ARE WHITE UNLESS OTHERWISE SPECIFIED
5. TOLERANCE 0"-3" ± 1/32 OVER 3" ± 1/16

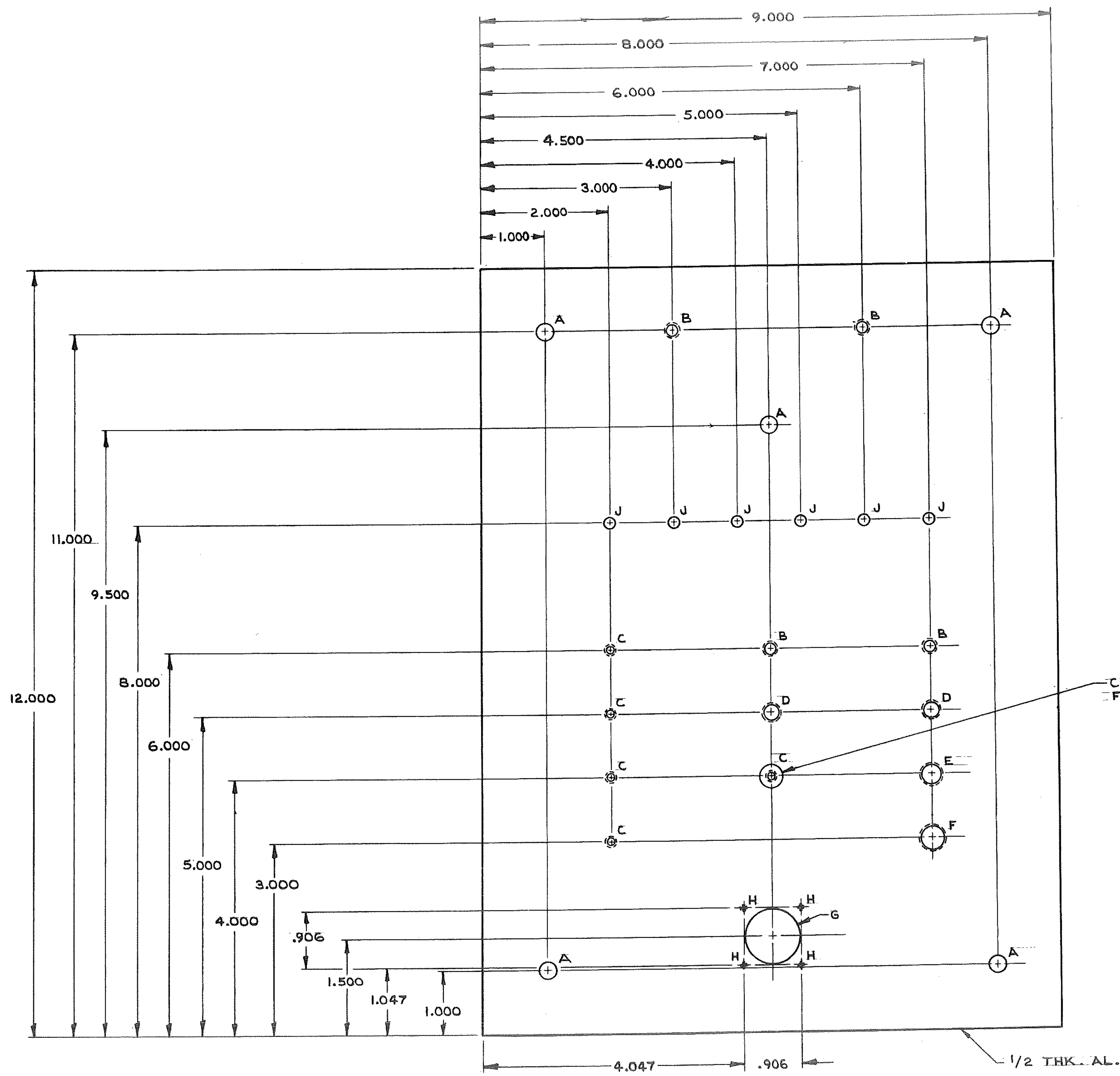
MARTIN MARIETTA, DENVER DIVISION R.C. 12/18/70

SIZE	CODE IDENT NO.	
D	04236	ASTRONAUT TOOL CARRIER-DETAILS
SCALE		RES 31683

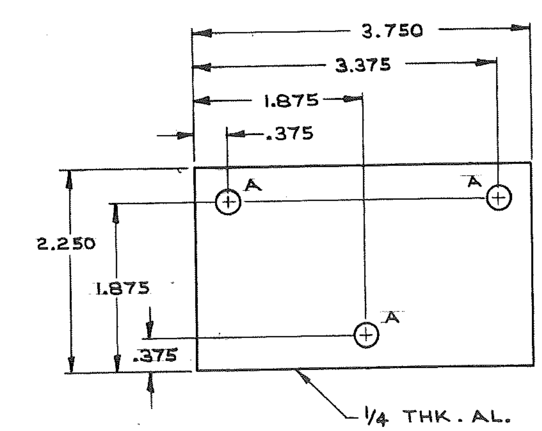
RES 31683


SST. HOLD-DOWN STRAP TYP.
#10-32 TEE-NUT (RECESSED) TYP.
#10-32 SCR. TYP.
3/4" WOOD SADDLE TYP.
RECESSED WOOD SCR. TYP.
SECTION A-A
SCALE: 1/2:1
WASHER
3/8 O.D. TUBE
1/2 THK. AL. PLATE
1/4-20 TEE-NUT (RECESSED)
1/4-20 BOLT
2 3/4
SECTION B-B
2 1/2
#10-32 TEE-NUT (RECESSED)
LOOP CLAMP-STD. No. 21919-4
3/8 O.D. TUBE
#10-32 HEX. HEAD SCR.
WASHER
SECTION C-C
2 3/4
#10-32 FIL. HEAD SCR. (RECESSED)
#10-32 FIL. HEAD SCR.
PHENOLIC
5/16 DIA. CLEARANCE HOLE FOR TUBE
SECTION D-D
SEE DRAWING No. RES-31691
1/4 SURFACE TENSION TEST
3/8 SURFACE TENSION TEST
1/2 SURFACE TENSION TEST
1/4 DIA.
3/8 DIA.
1/2 DIA.
12
INSTALL WIRES IN CONNECTOR & POT WITH MMS-138A SILICONE
FASTENER TASK PANEL
BENDIX MALE CONNECTOR No. 81D28P14-125W WITH FEMALE No. 81D28R
WIRES TO BE 34" LONG
4 PIECES REQD.
LEAK SEAL REPAIR
UNION (OR REDUCER AS REQD.) TYP.
CAP (TYP.)
TEE COUPLING (TYP.)
RESTRAINT HANDLE TYP.
ZERO-G INDICATOR (POLYSTYRENE BALL)
NITROGEN PRECHARGE PRESSURE
REPUBLIC RELIEF VALVE No. 629XB-3-4-2 (RELIEF PRESSURE SET AT 80 PSIG WITH RESEAT PRESSURE AT 76 PSIG)
75 PSI RELIEF
CV-1
NITROGEN LOADING PORT
H2O TANK
MARSH INSTRUMENT CO. 3 1/2" TYPE 1-CFPR-1/4" PRESSURE GAUGE - TYP. (2) PLCS.
H2O SYSTEM PRESSURE
CV-4
CROSS (TYP.)
REPUBLIC TWO-WAY HAND VALVE No. 5135-4SSP - TYP. (5) PLCS.
CV-3
CV-2
H2O LOADING PORT
APM FILTER No. AC-860-12NB
COMPONENT REPLACEMENT
FLUID REMOVAL TEST POINT
CV-5
3/4 x 3/4 AL. ANGLE
39 1/2 x 48 x 5/8 THK. PLYWOOD
TASK PANEL LAYOUT
RES-31690
M. HUSSEY
2/11/71

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED



HOLE LETTER	HOLE DIA. OR THD. CALL-OUT (HELI-COIL)
A	.281 DIA. THRU
B	1/4 - 28 UNF
C	#10 - 32 UNF
D	5/16 - 24 UNF
E	3/8 - 24 UNF
F	7/16 - 20 UNF
G	7/8 DIA. THRU
H	#4 - 40 UNC
J	3/16 DIA. SRING PIN



FASTENER PANEL
2/22/71

SIZE	CODE IDENT NO.	
D	04236	RES-31691
SCALE FULL	M. HUSSEY	SHEET

CHG

OEN 061607-01 (10-68)